

HIAPER Pole-to-Pole Observations 2009 (“HIPPO”)

Steven C. Wofsy

Overview of mission framework
and observations

Brooks Range, AK

HIPPO (HIAPER Pole-to-Pole Experiment)

- **Science Objectives:**

Utilize observed distributions of major greenhouse gases to help determine the continental-scale sources and sinks of major greenhouse gases.

- **Motivation:**

Models obtained the global distributions of surface fluxes for GHGs by optimizing *a priori* emission rates to match time series observations at surface stations.

- **Result:**

Models fit the data! But they give very different results for the optimal fluxes ☹ ... even *using the same data and flux regions [TRANSCOM 3]*.

- One factor: different vertical mixing [Stephens et al. 2007].
- Another: spatial/temporal distributions of surface flux.

Transport rates (emergent property) and spatial distributions of surface flux are not readily optimized in inverse analyses.

- The distributions of atmospheric gases arise from transport on all spatial and temporal scales, acting on the sources and sinks at the surface and in the atmosphere.
- Measured concentrations are *emergent properties, neither represented explicitly nor computed directly in models, but arising from the ensemble of processes directly designed into models.*

What HIPPO is intended to accomplish:

- *Decisively change the predicament where data deficits hold back atmospheric science by greatly enhancing the observations of atmospheric concentrations at altitude and at the surface in critical areas of the globe that are difficult to reach otherwise (e.g. the southern Ocean).*

Surface networks: (almost) global; sustained over time.
No vertical structure, limited resolution of horizontal gradients, key regions not sampled (e.g. Southern Ocean).

Satellite Data: (almost) global; moderately sustained.
Poor resolution of *vertical distributions in the troposphere*; cannot view *cloudy* (e.g. ITCZ) or *polar* regions.

Aircraft Data: fine grained, (may) cover the vertical profile.
Infrequent, “one shot”, short-term, limited areas.

HIPPO, is a new type of data set:
global and extremely fine grained. Detailed vertical and horizontal gradients. Repeated 5 times for all seasons; very wide range of constituents.

GEOSECS is a role model for **HIPPO**. Cross Sectional Data to assess and challenge models, develop new questions, test ideas, and provide a reference data set for detection of future change. Requires absolutely calibrated data, repeated very long transects, comprehensive tracer suite for applications not yet envisioned.

Comparing the Observed and Modeled Gradients

- 3 models that most closely reproduce the observed annual-mean vertical CO₂ gradients (4, 5, and C):

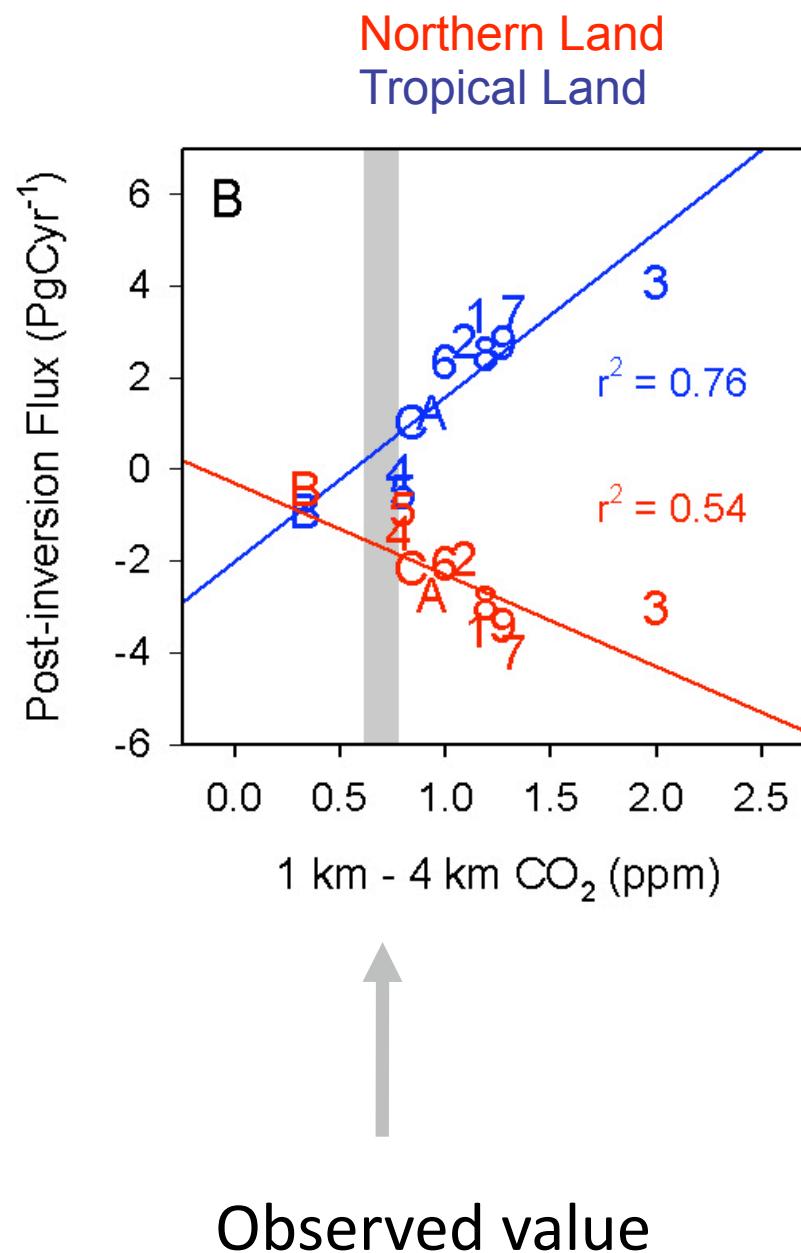
Northern Land =
 $-1.5 \pm 0.6 \text{ PgCyr}^{-1}$

Tropical Land =
 $+0.1 \pm 0.8 \text{ PgCyr}^{-1}$

- All model average:

Northern Land =
 $-2.4 \pm 1.1 \text{ PgCyr}^{-1}$

Tropical Land =
 $+1.8 \pm 1.7 \text{ PgCyr}^{-1}$



Most of the models overestimate the annual-mean vertical CO₂ gradient

Slide courtesy Britt Stephens (NCAR)

HIPPO Aircraft Instrumentation

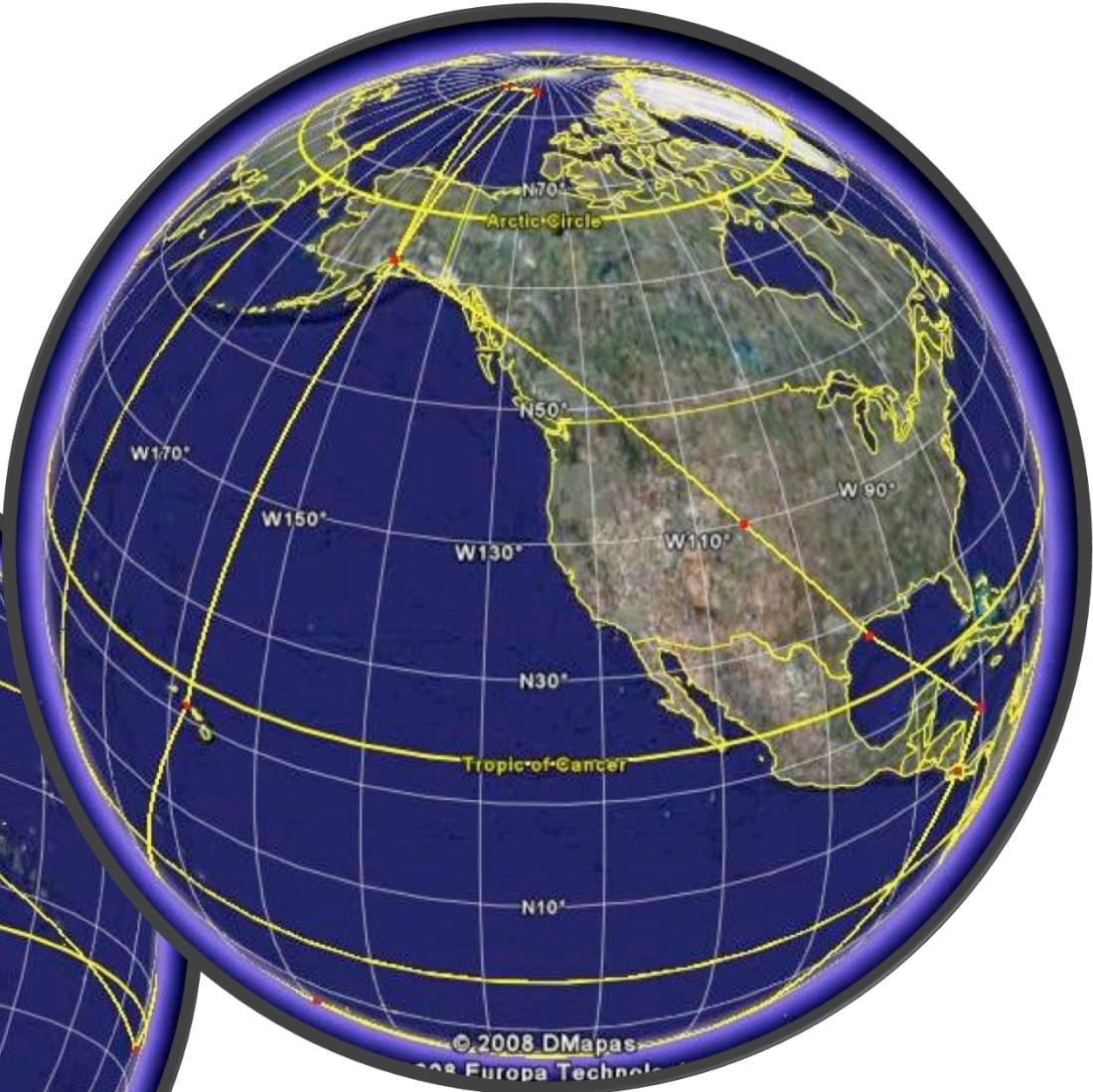
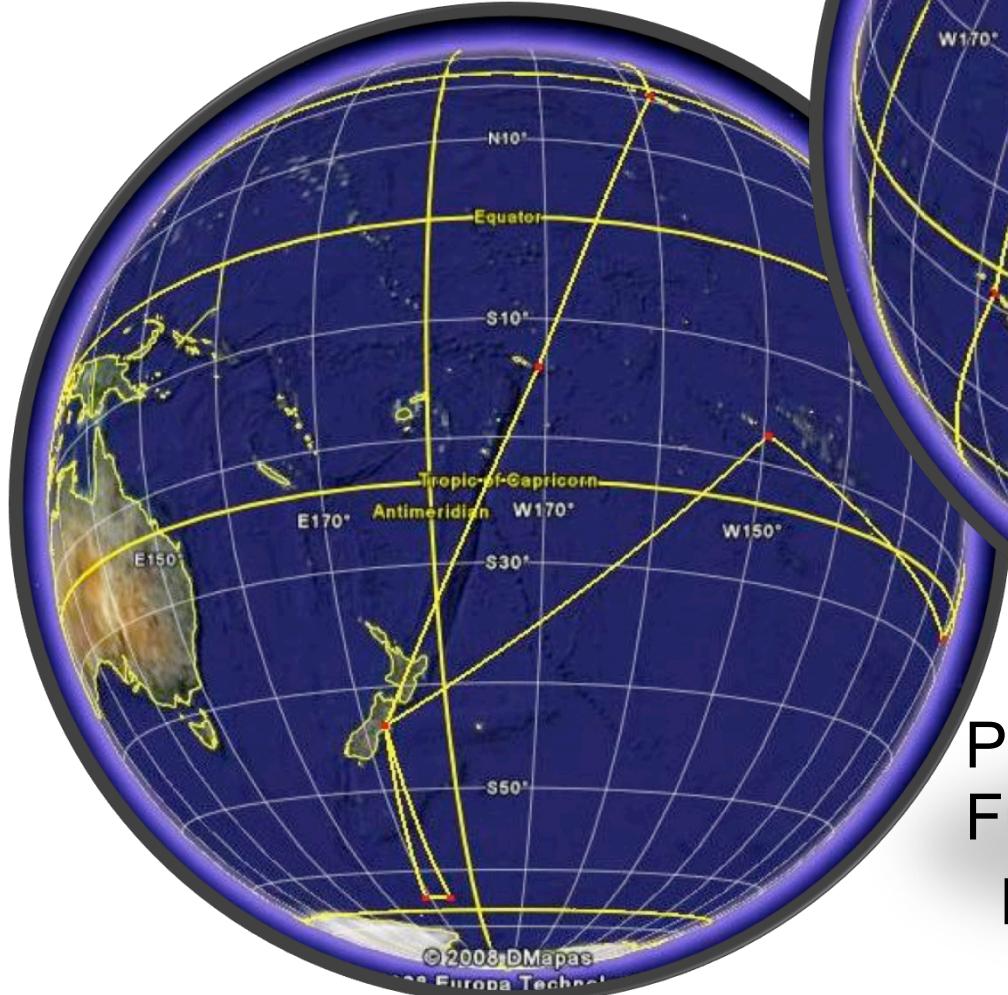
Harvard/Aerodyne—HAIS QCLS	CO_2 , CH_4 , CO , N_2O (1 Hz)
NCAR AO2	$\text{O}_2:\text{N}_2$, CO_2 (1 Hz)
Harvard OMS CO_2	CO_2 (1 Hz)
NOAA CSD O_3	O_3 (1 Hz)
NOAA GMD O_3	O_3 (1 Hz)
NCAR RAF CO	CO (1 Hz)
NOAA- UCATS, PANTHER GCs (1 per 70 – 200 s)	CO , CH_4 , N_2O , CFCs, HCFCs, SF_6 , CH_3Br , CH_3Cl
Whole air sampling: NWAS (NOAA), AWAS (Miami), MEDUSA (NCAR/Scripps)	 $\text{O}_2:\text{N}_2$, CO_2 , CH_4 , CO , N_2O , other GHGs, COS , halocarbons, solvent gases, marine emission species, many more
Princeton/SWS VCSEL	H_2O (1 Hz)
NOAA SP2	Black Carbon (1 Hz)
MTP, wing stores, etc	T, P, winds, aerosols, cloud water

HIPPO_1 Global Mission:

09 – 30 January 2009

46 000 km

135 Vertical Profiles



Platform: NCAR Gulfstream V
Funding: National Science Fdn
plus: NOAA, NASA, Harvard

1 Regional (N. Am, “Pre-HIPPO”)
5 global missions

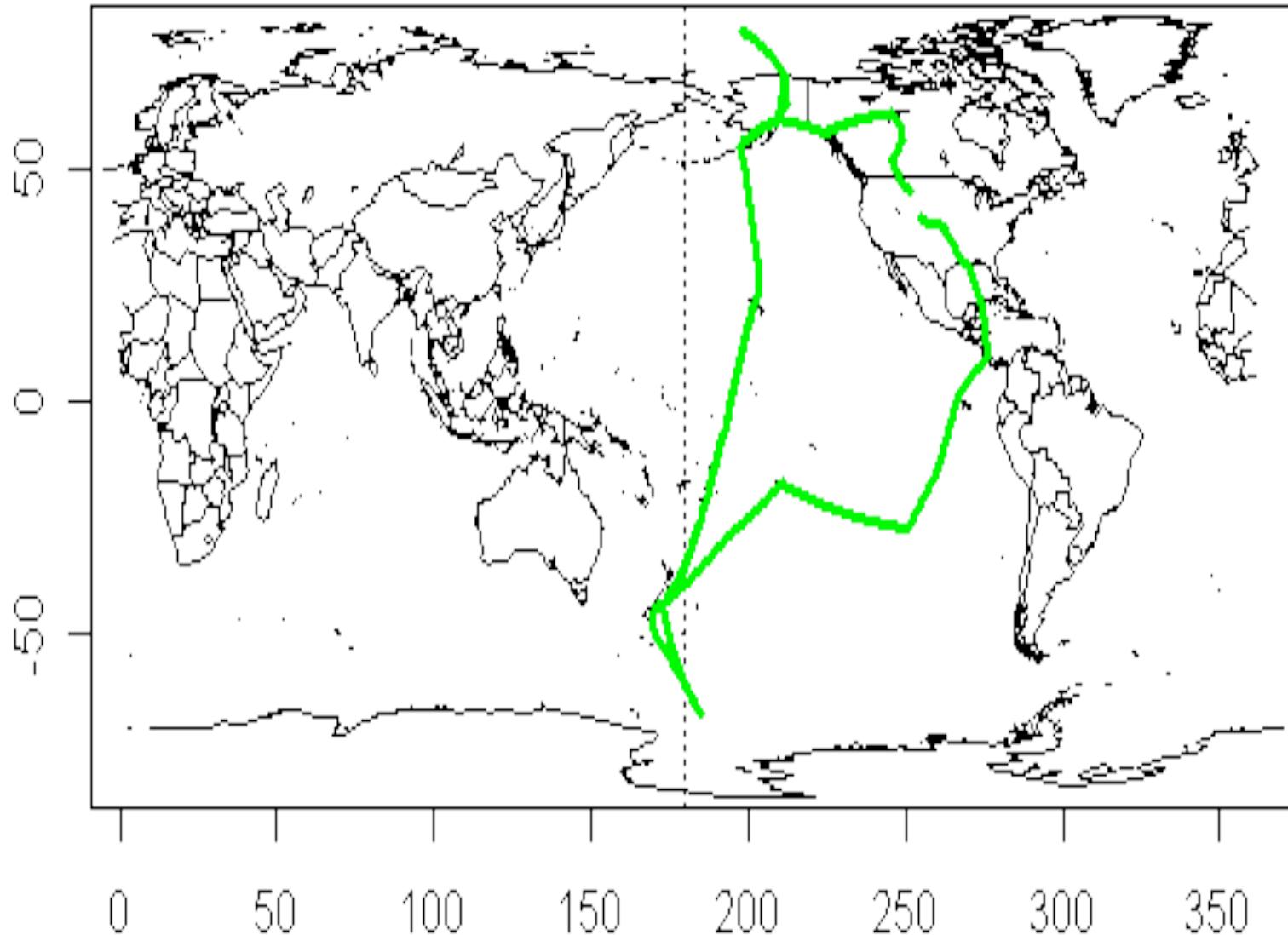


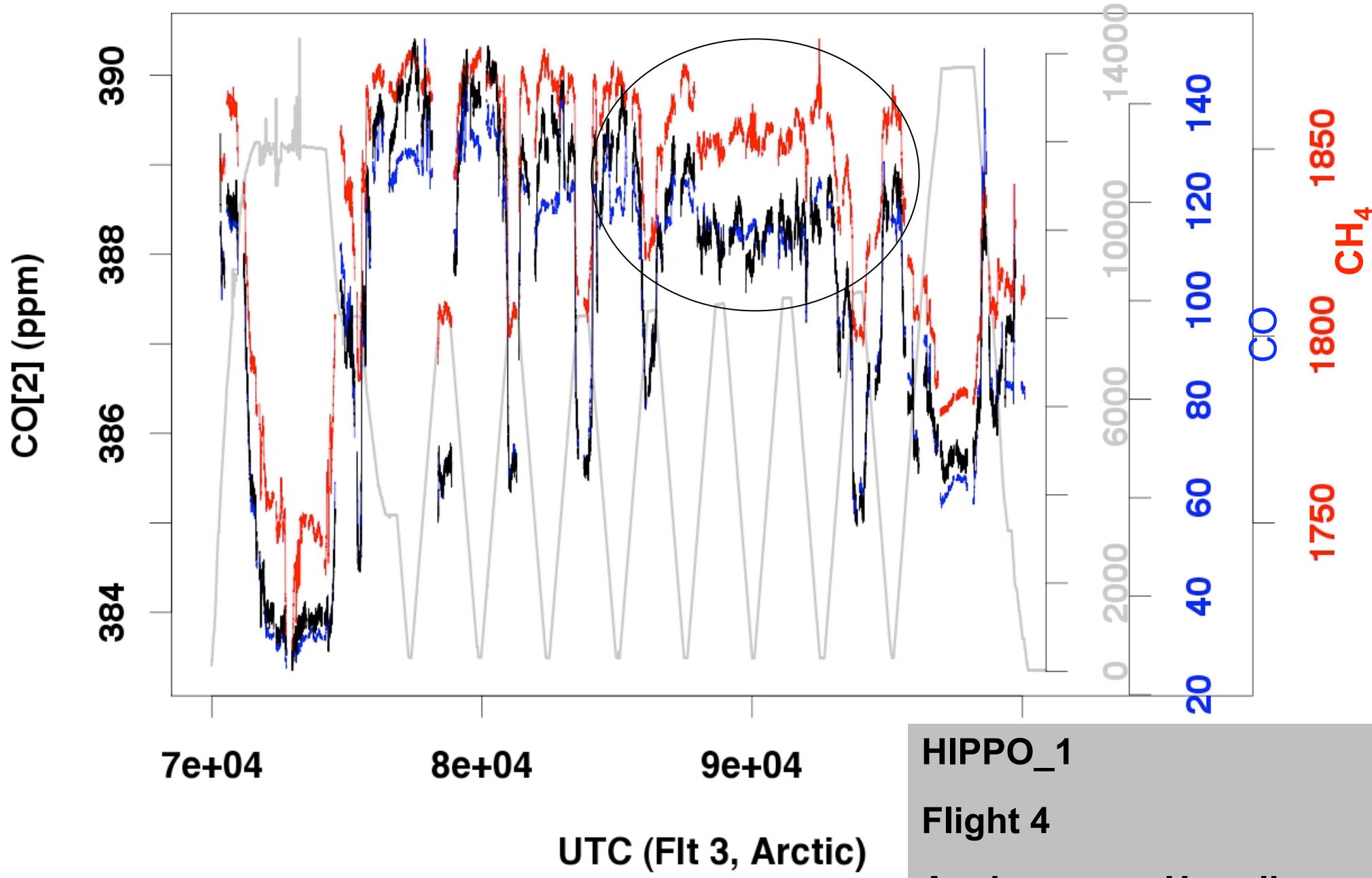
Shadow of the Earth
visualized by ice
crystals over the
Alaska range.

Pago Pago, Samoa



HIPPO completed the 1st of 5 global surveys in January, 2009





HIPPO_1

Flight 4

Anchorage -> Hawaii

14 January 2009

400-599mb
600-799mb
800-950mb

January
15, 2009

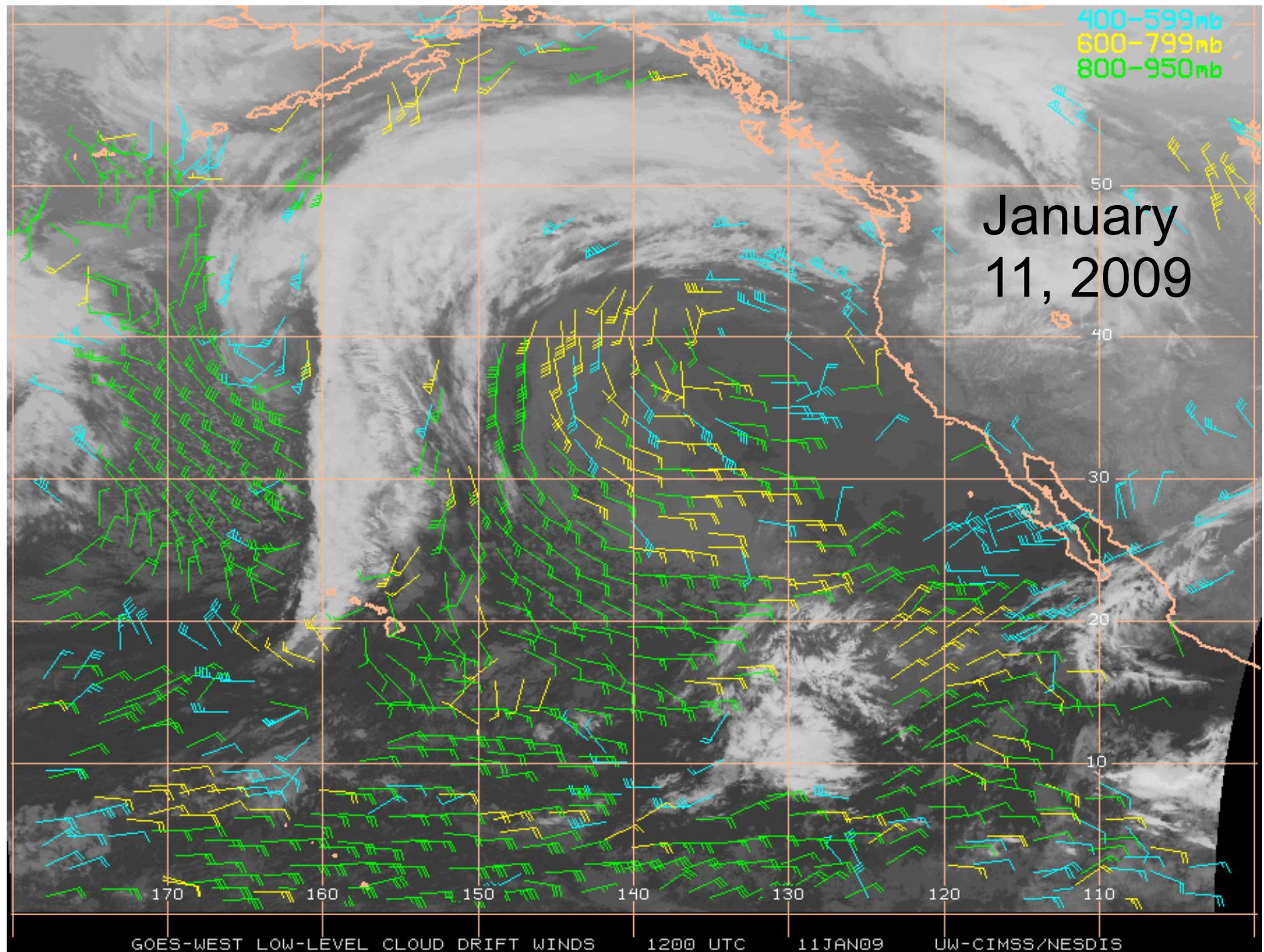
000 UTC

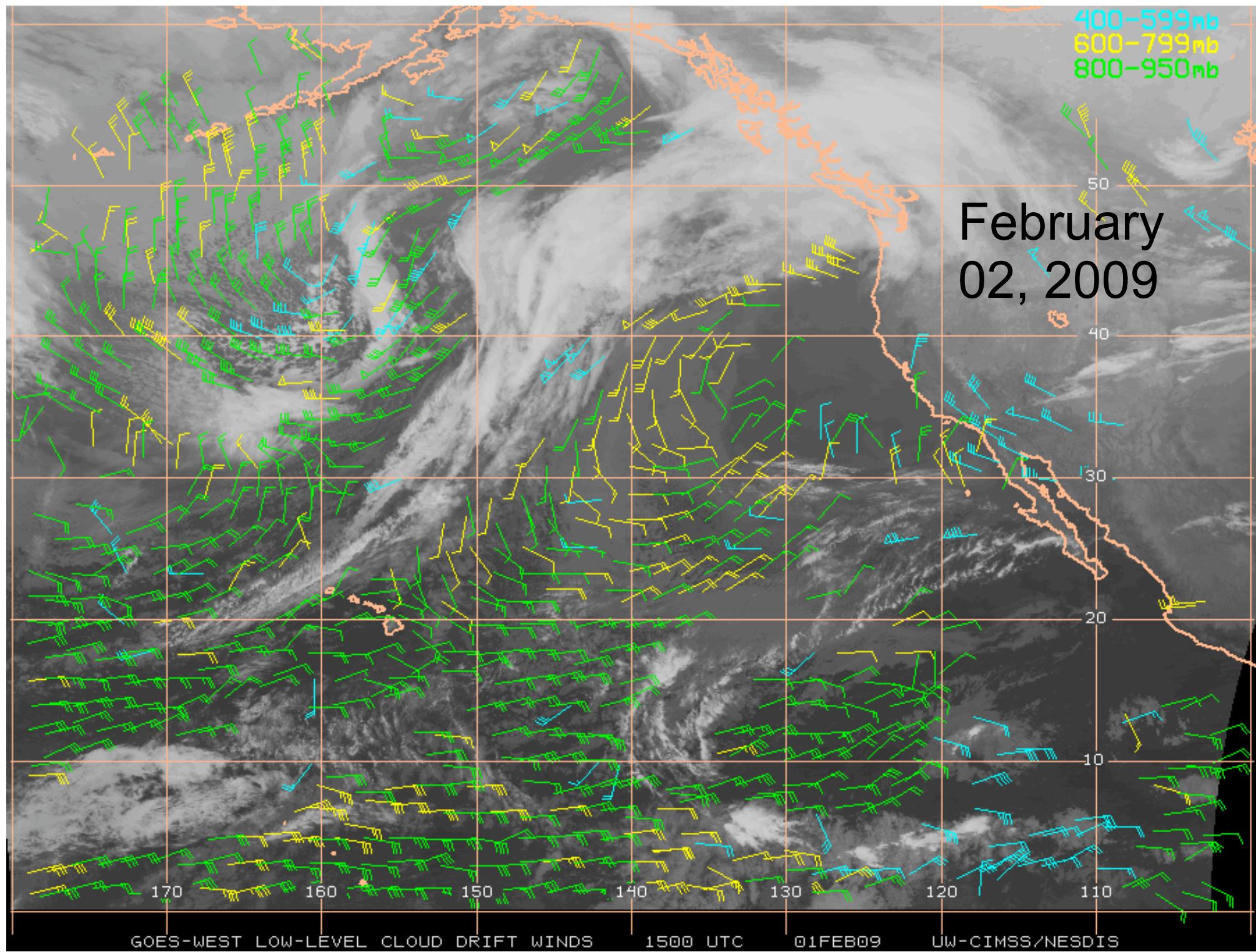
GOES-WEST LOW-LEVEL CLOUD DRIFT WINDS

0000 UTC

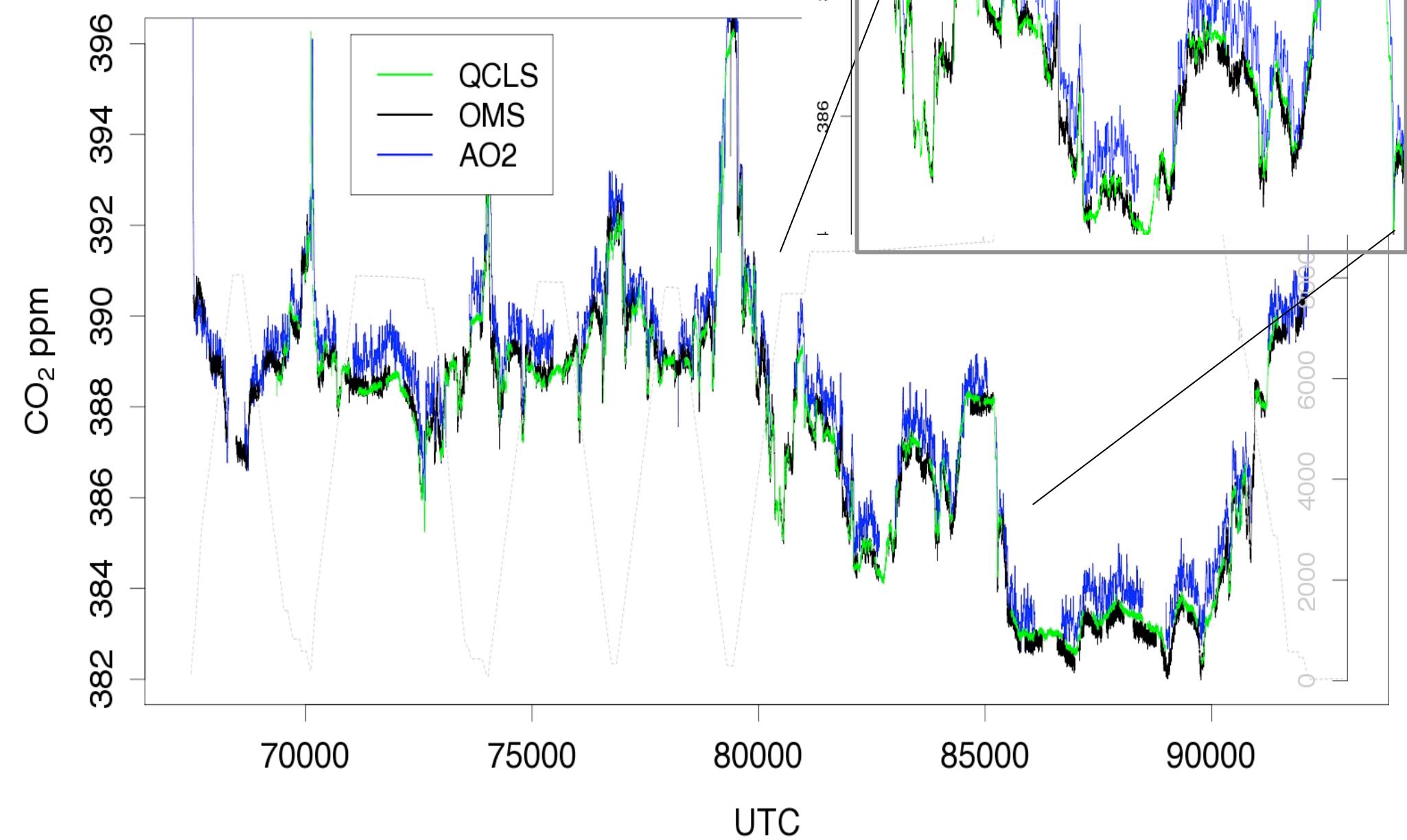
15JAN09

UW-CIMSS/NESDIS

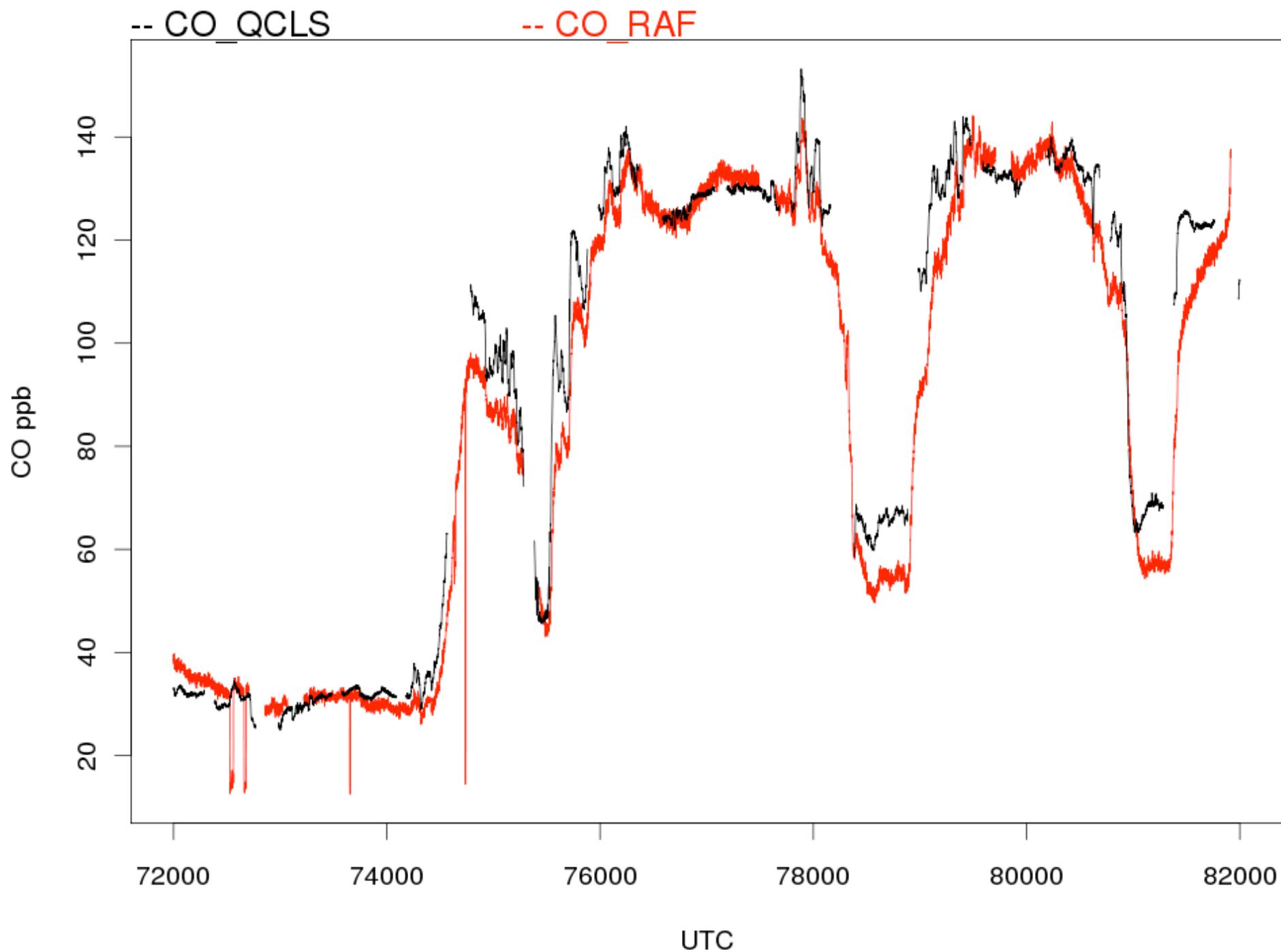


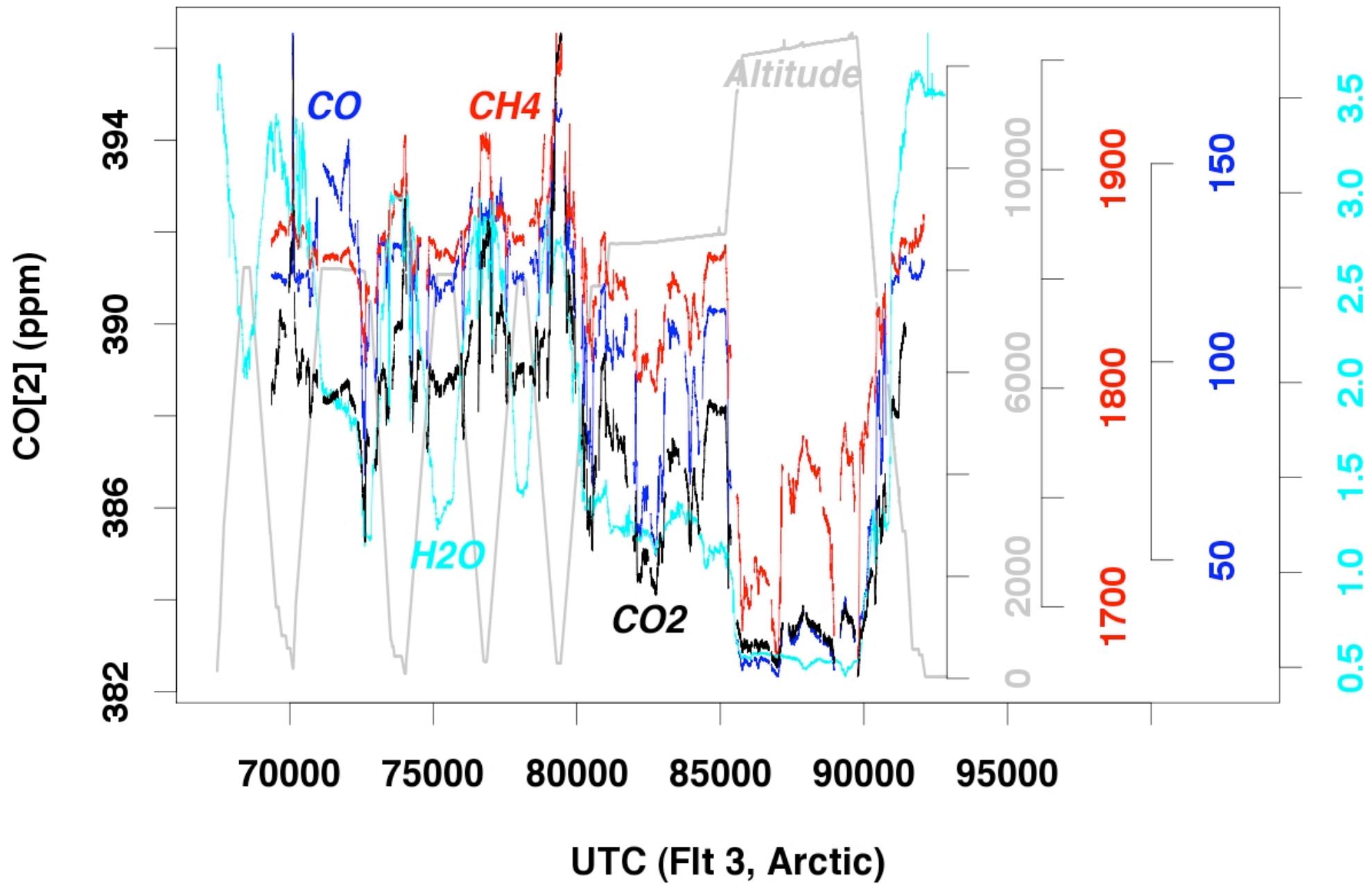


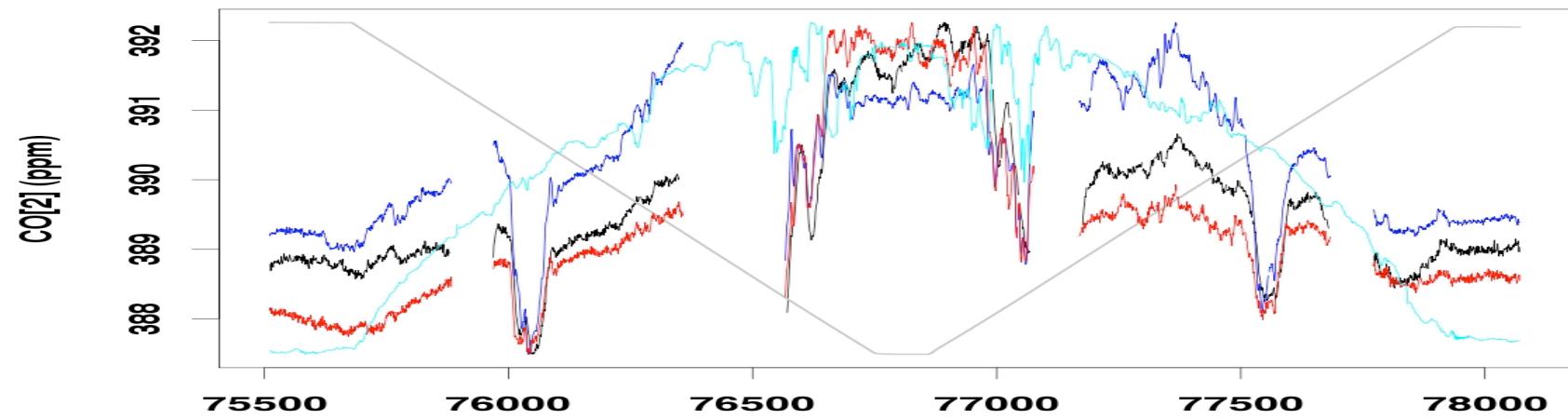
Arctic flight – RF03



Detail RF 4







Tracers vs Alt, Flt 3, 75500 - 78100

388

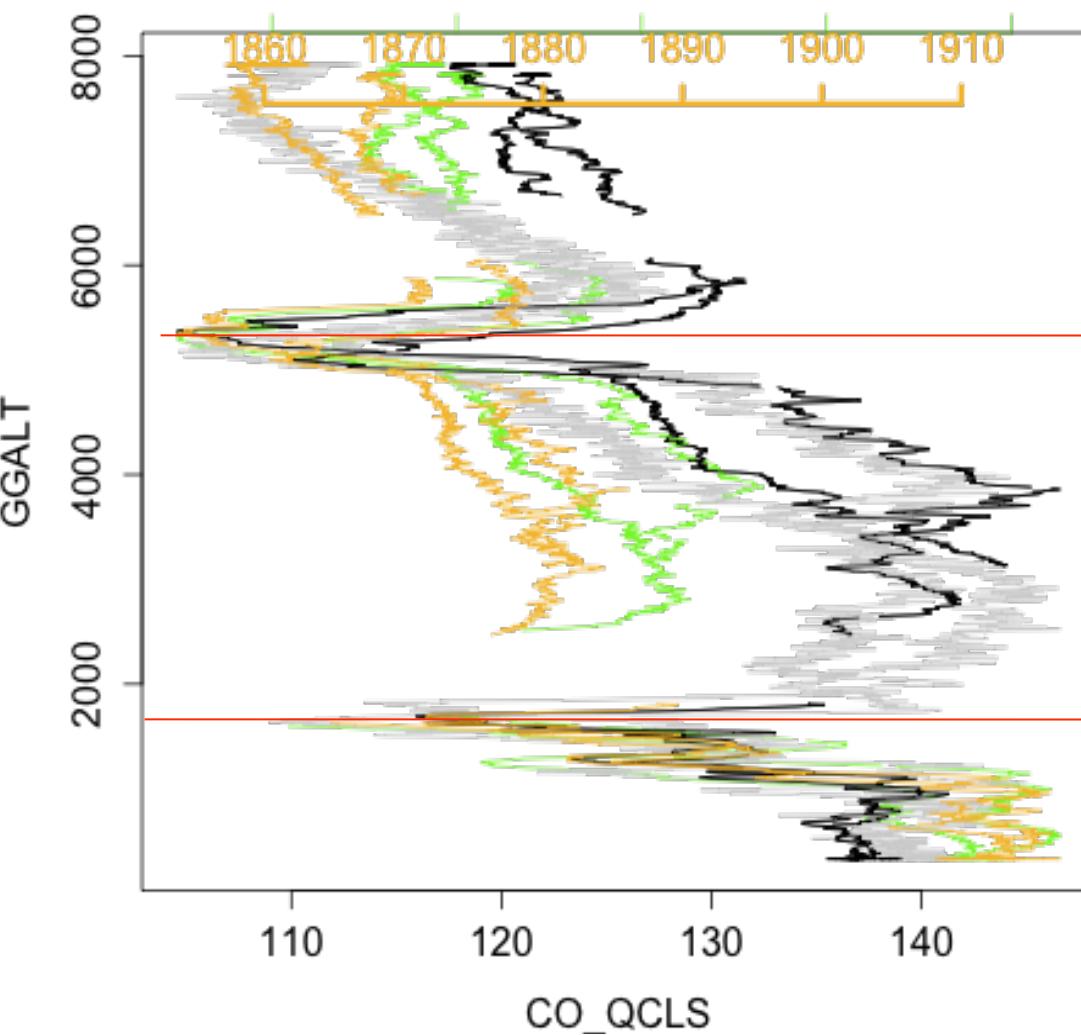
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390

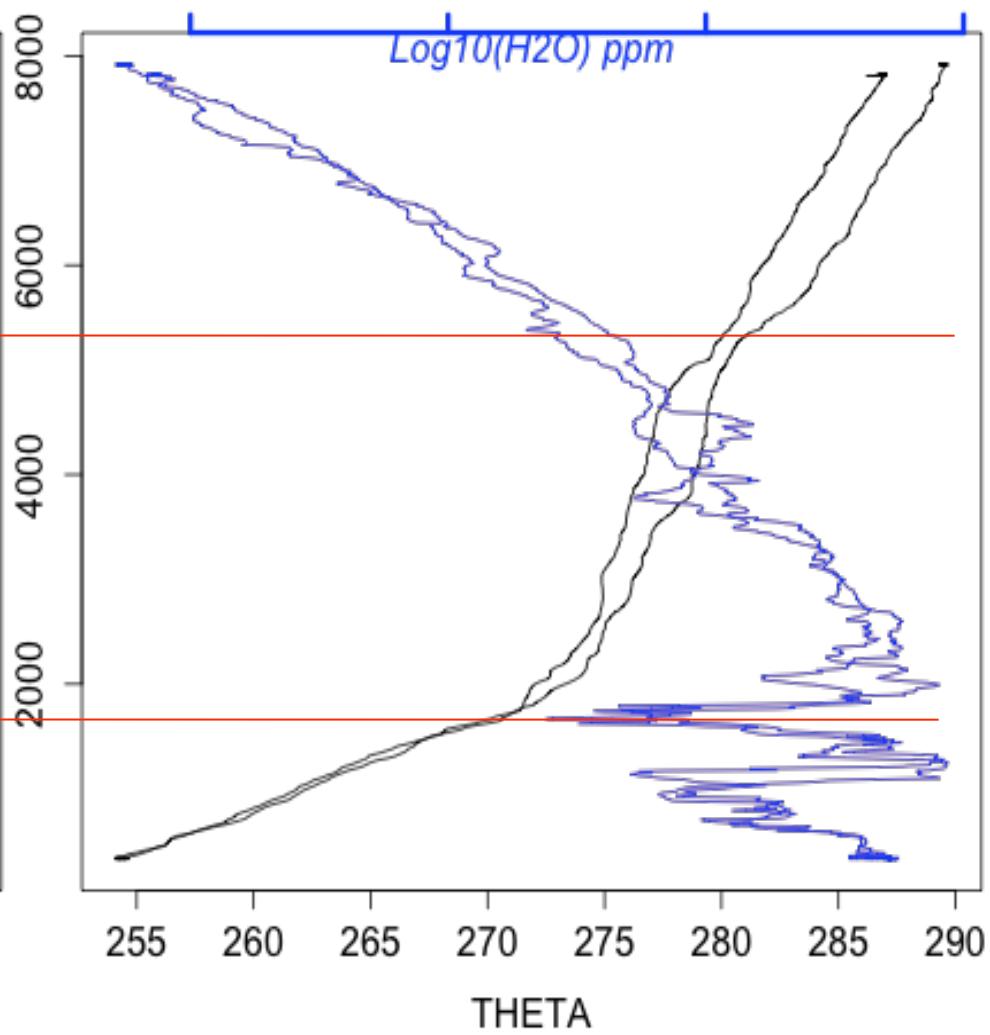
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392

77500 78000



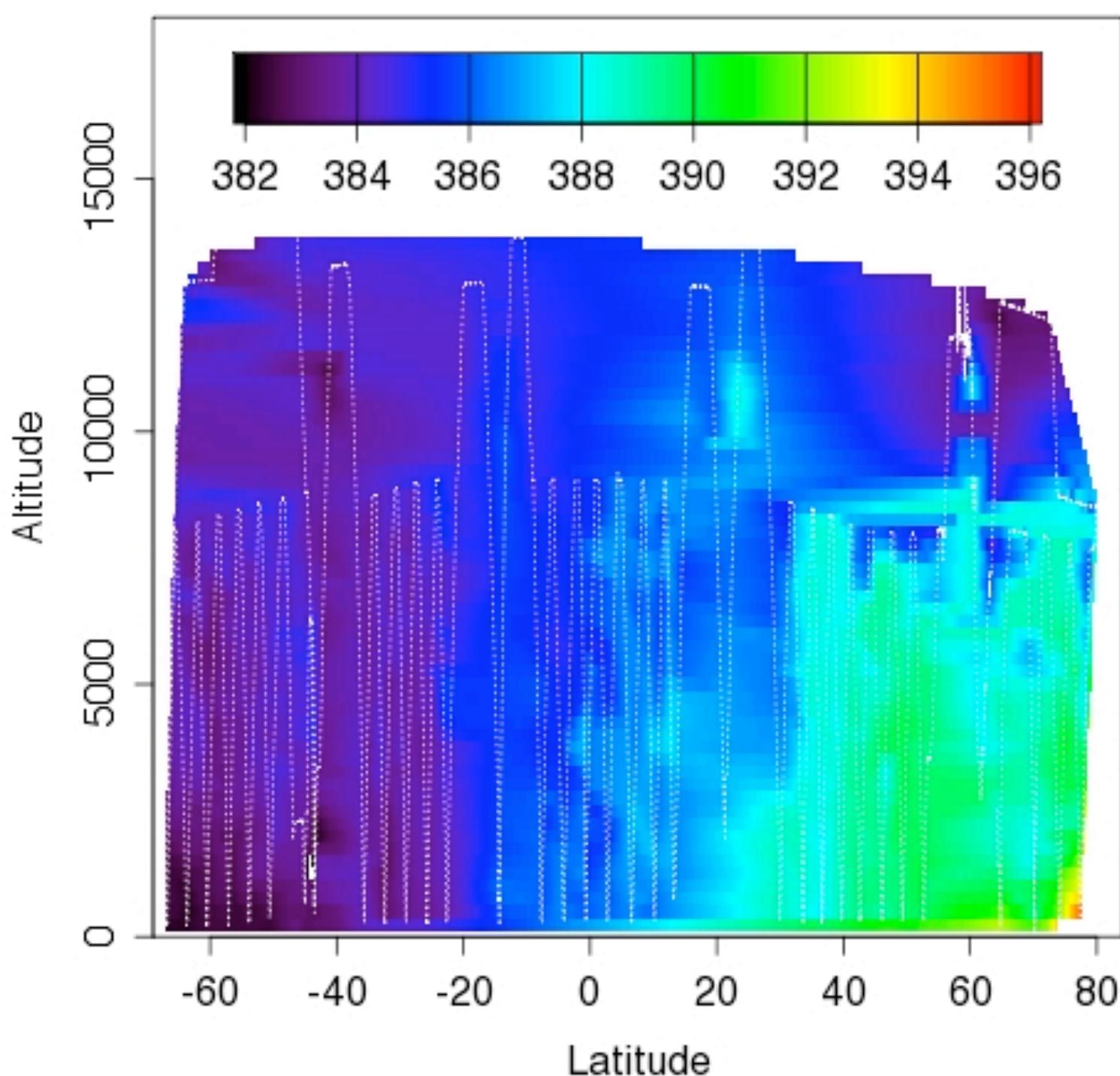
CO_QCLS



THETA

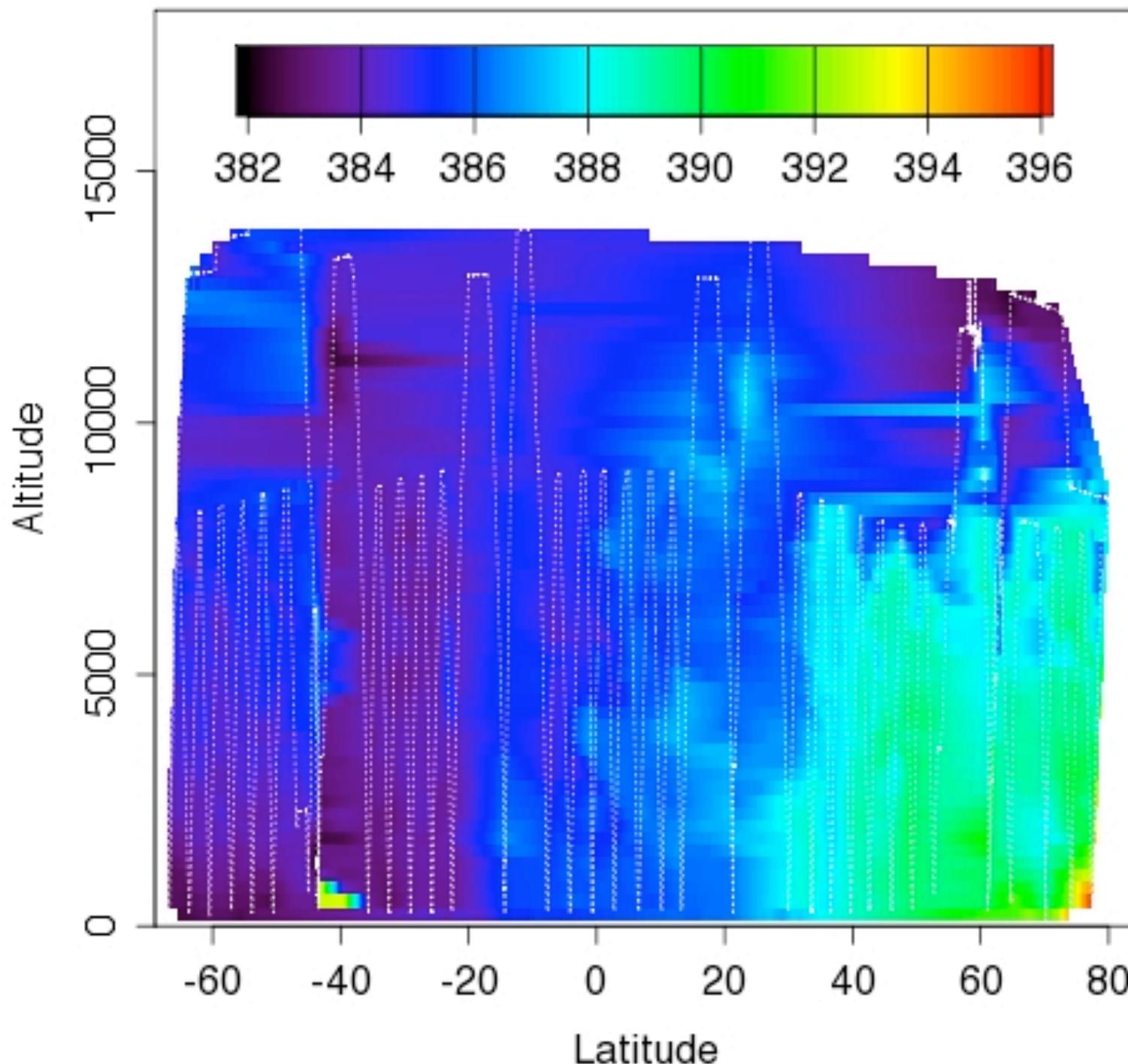
CO₂_QCLS

Flts 3 4 5 6 7



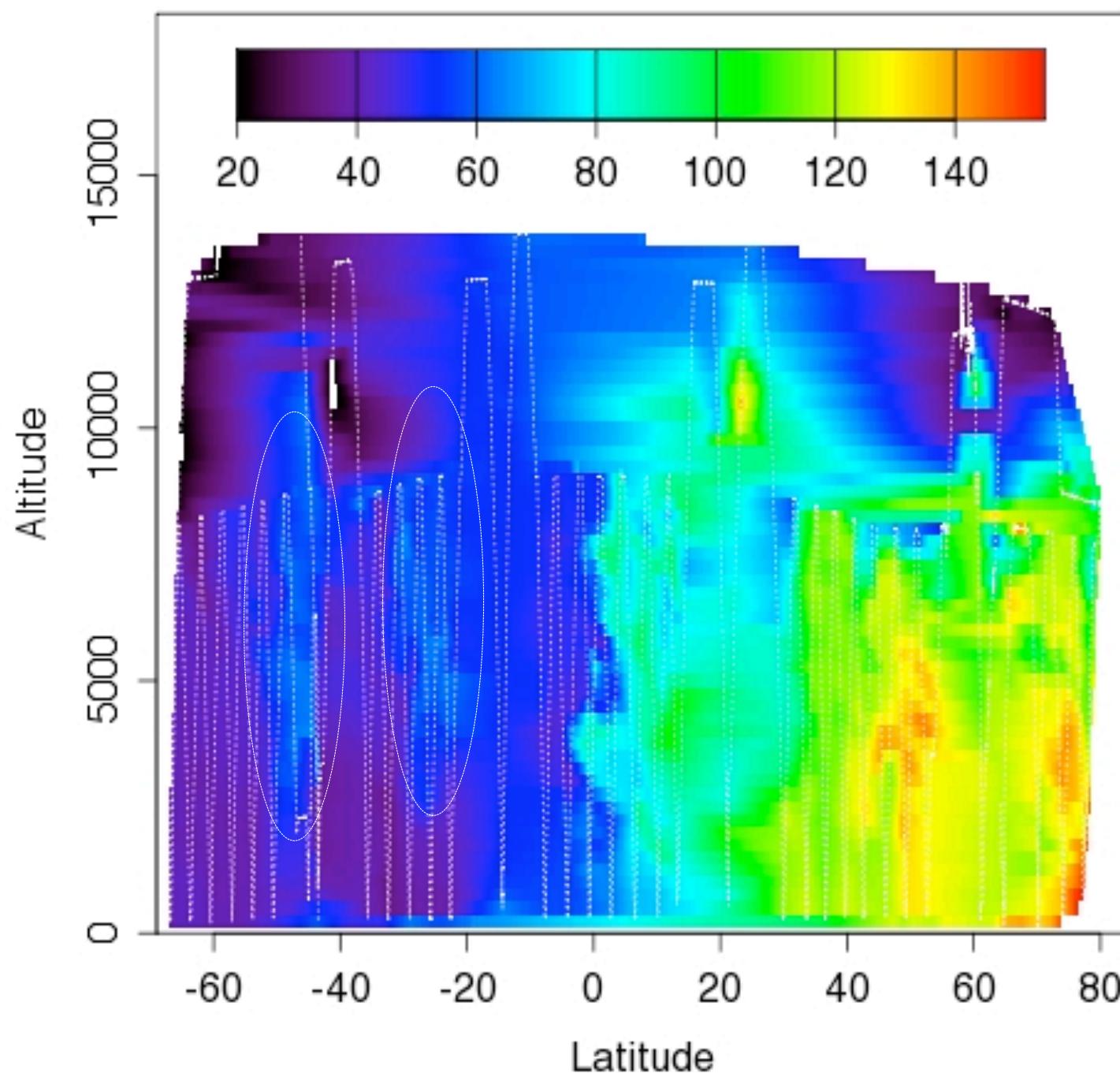
CO₂_OMS

Flts 3 4 5 6 7



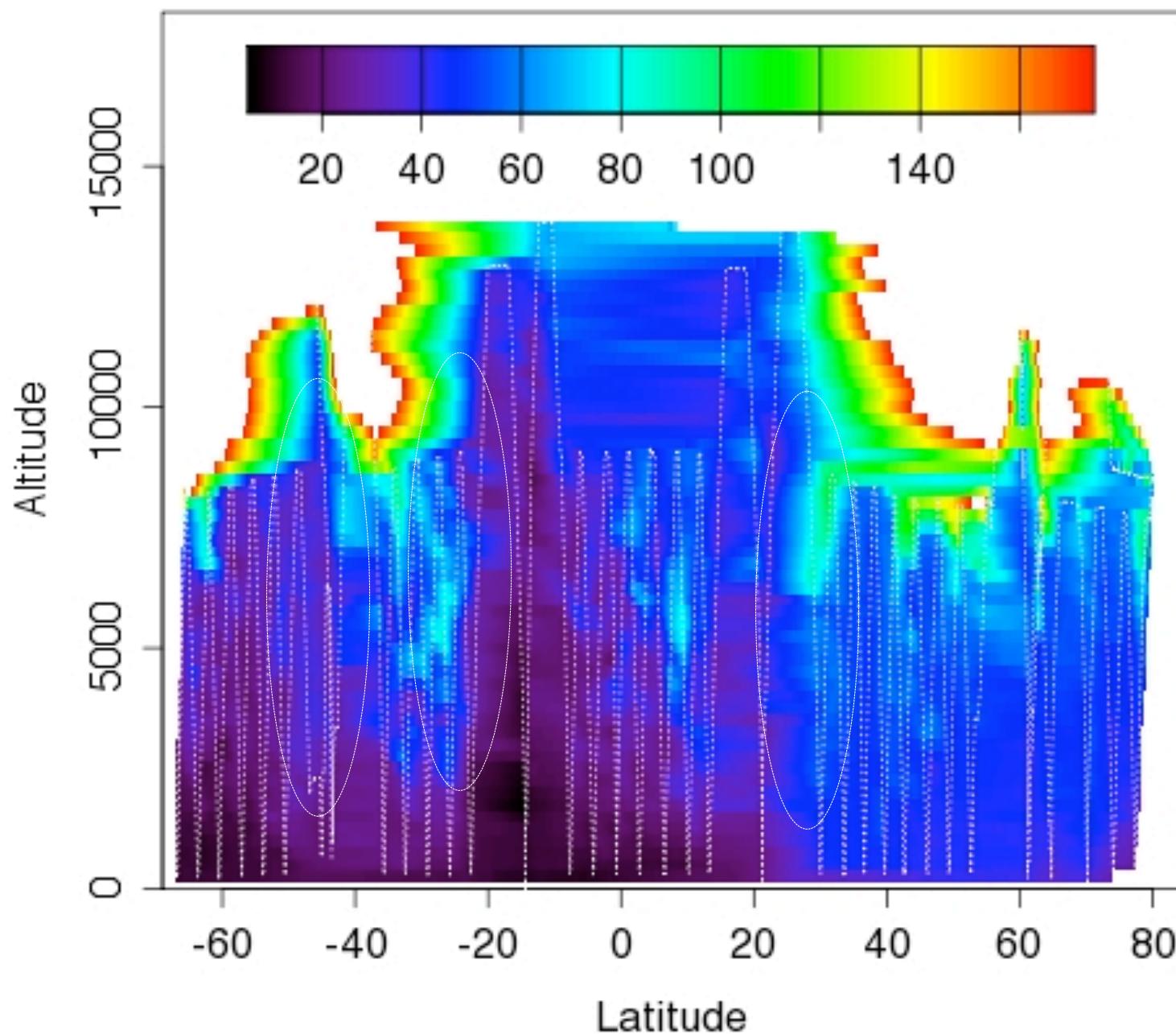
CO_QCLS

Fits 3 4 5 6 7

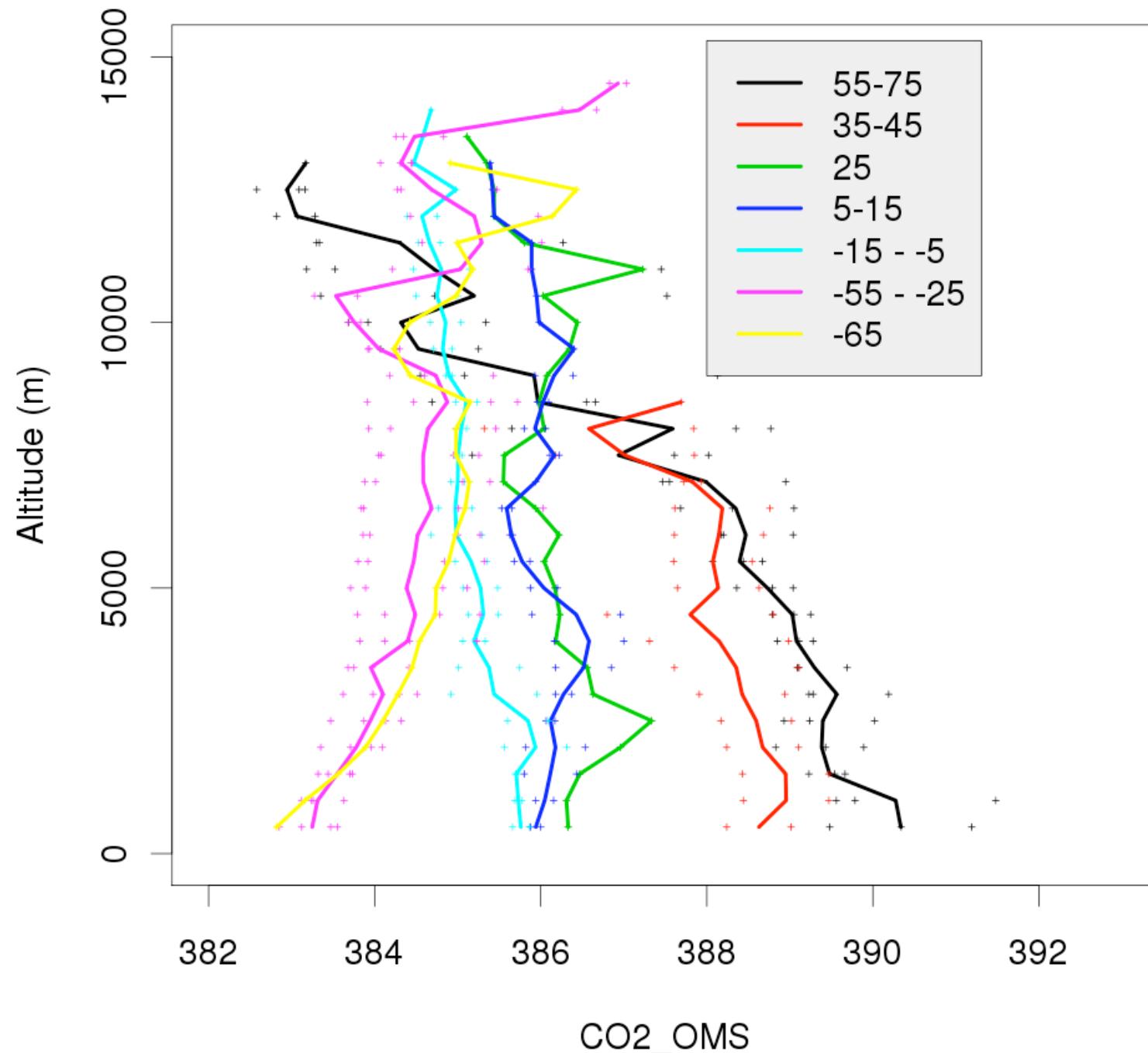


O3_UCATS

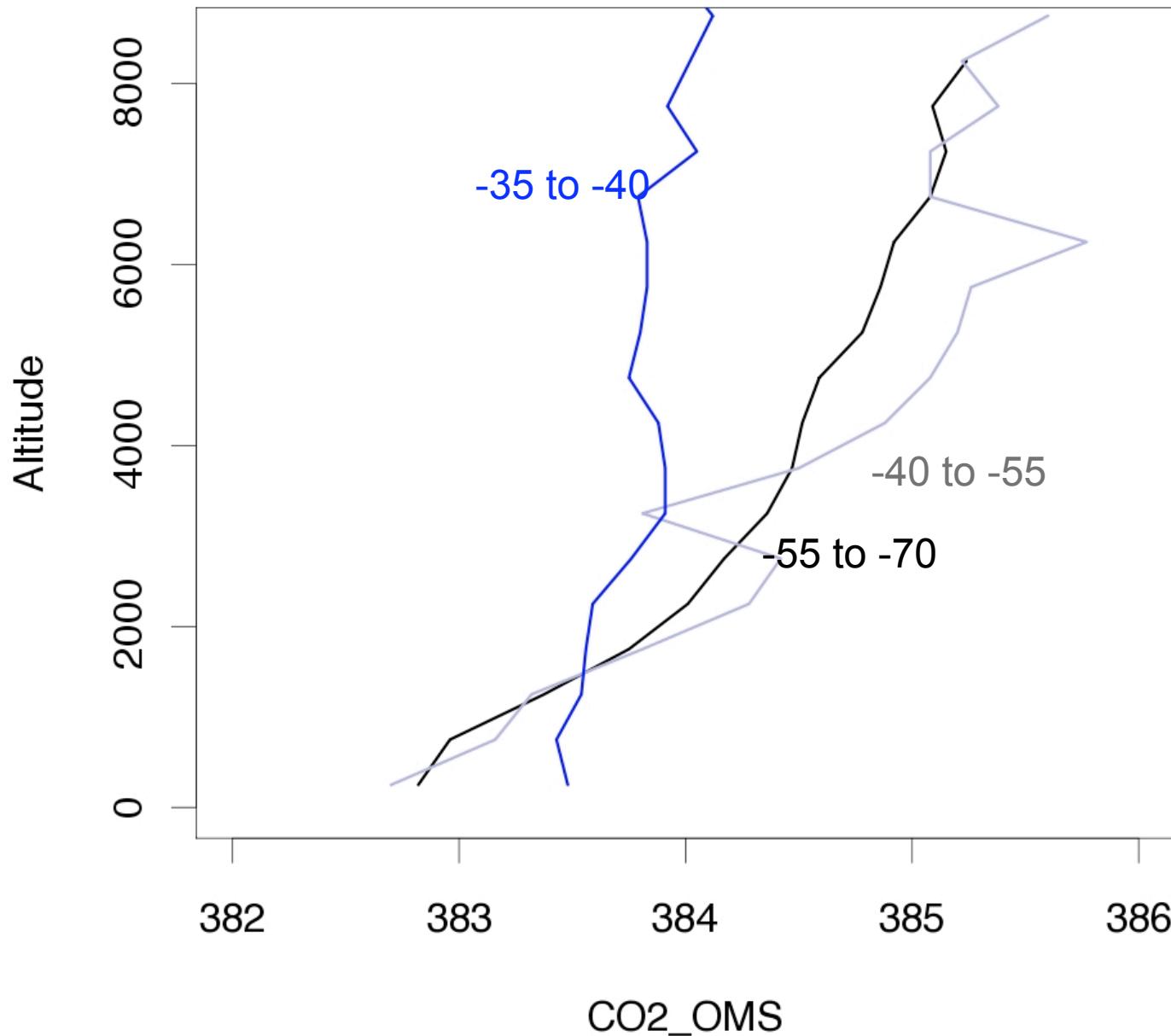
Flts 3 4 5 6 7



CO₂ HIPPO_1 Pacific transect



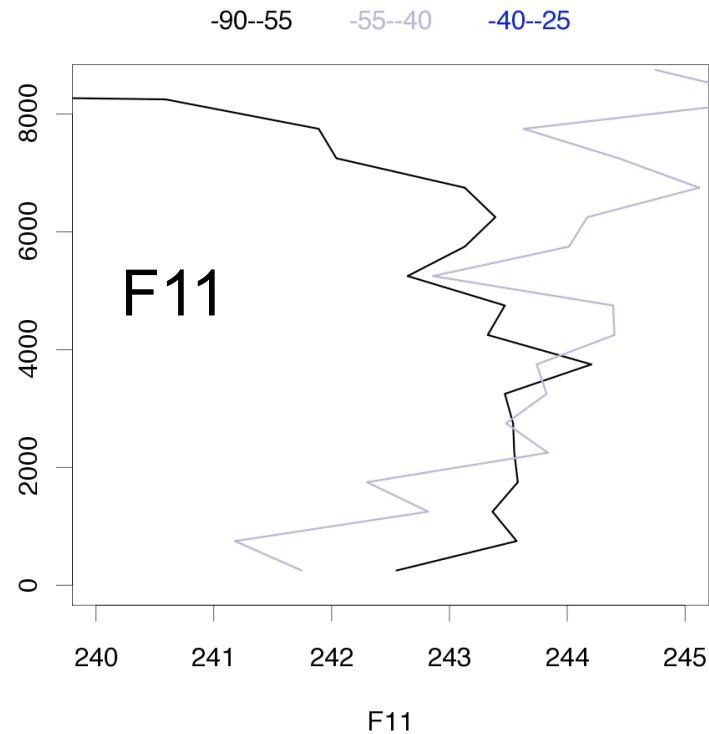
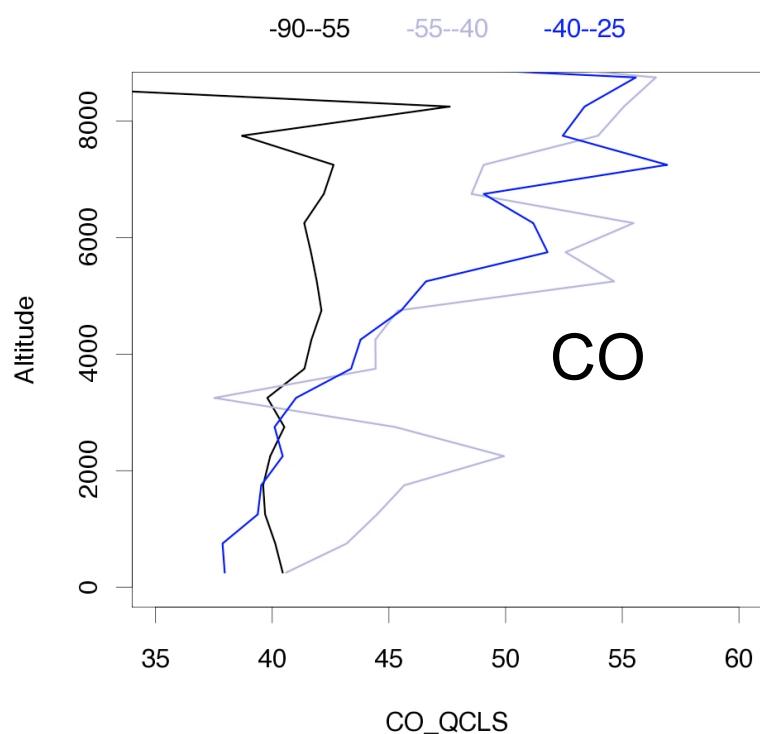
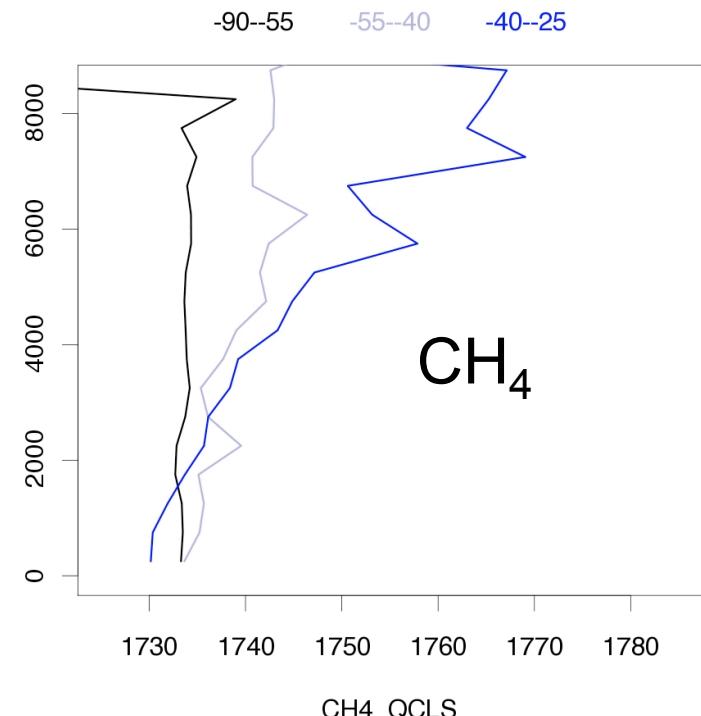
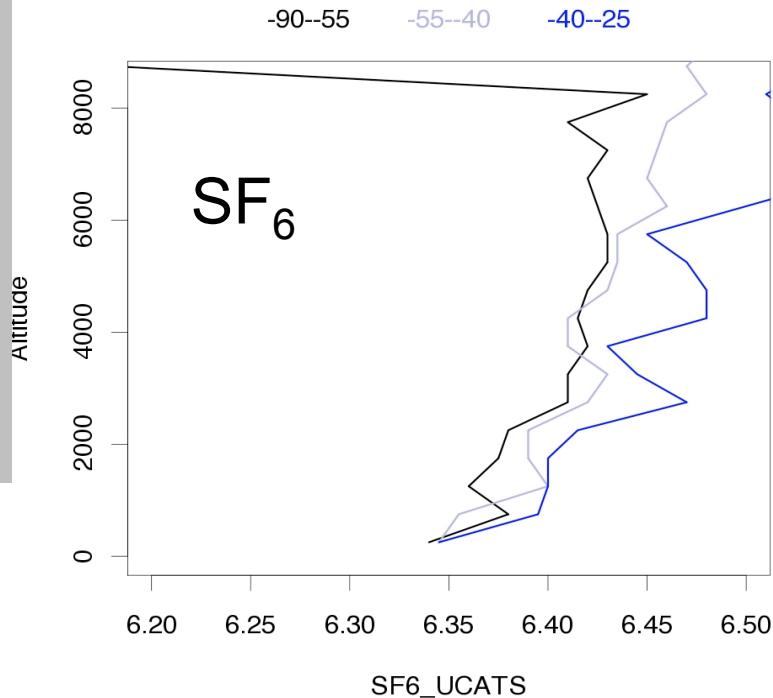
CO_2 vertical gradients in Southern high latitudes



Profiles of GHGs and related gasses over the Southern Ocean

Degassing vs. biological net production...

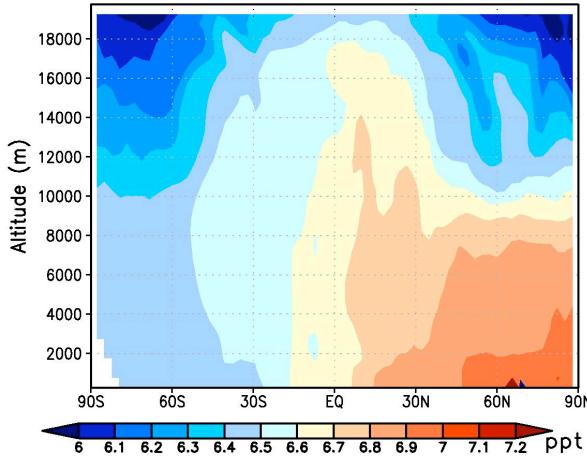
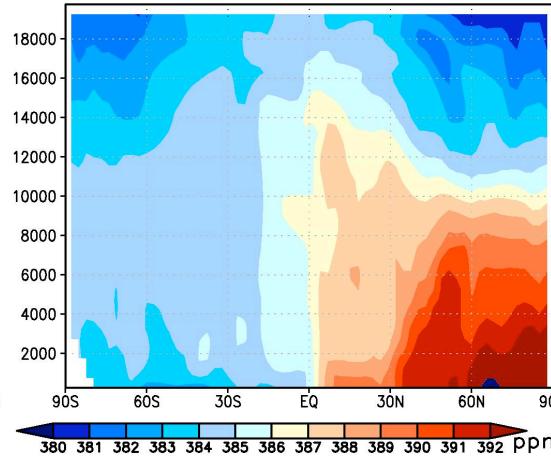
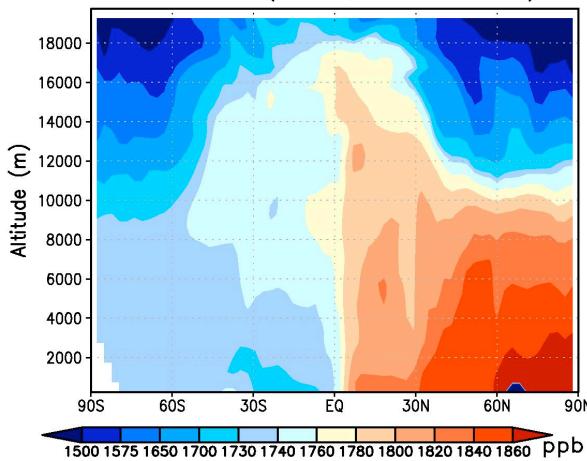
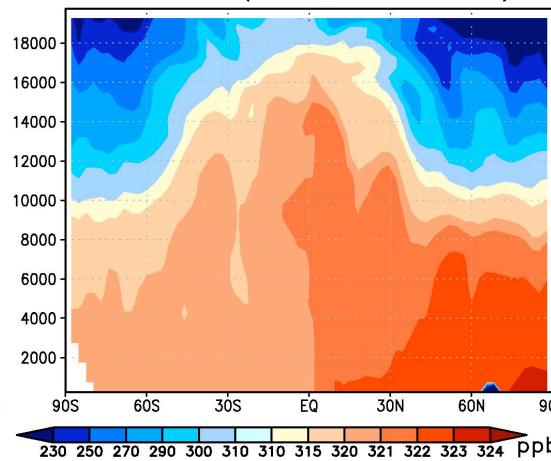
CO source?



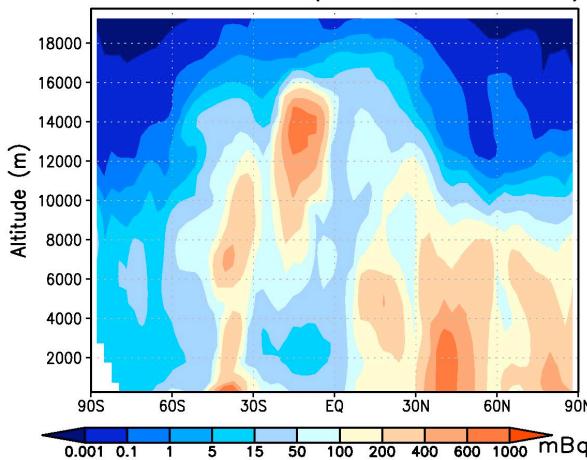
CCSR/NIES/FRCGC AGCM-based CTM (ACTM)

- ACTM is run in online mode at resolution T42 L67 (top 90km) *Prabir Patra*
- JRA-25 reanalysis meteorology (U,V,T nudged) *Kentaro Ishijima*
- Hadley Centre Sea-Surface Temperature & Sea-Ice Cover (prior to 2009)
- Salient features of ACTM (see Patra et al., ACP, 2009)
- CH_4 and N_2O chemistry (Sander et al., JPL Pub. 06-2, 2006)
- OH and Cl radicals are taken from CHASER/STRAT (Sudo et al., Takigawa et al.) models at monthly intervals
- O^1D and photolysis calculated online in the model
- SF_6 surface fluxes from EDGAR4.0 (Patra et al., ACP, 2009)
- CO_2 fluxes from EDGAR3.2 fossil, cyclostationary inversion using TransCom-3 models (Niwa/Patra et al., ICDC-8)
- CH_4 fluxes from EDGAR3.2 and GISS (Patra et al., JMSJ, 2009)
- N_2O fluxes from EDGAR3.2 and Nevison et al. ocean (Ishijima et al., JGR, submitted, 2009)

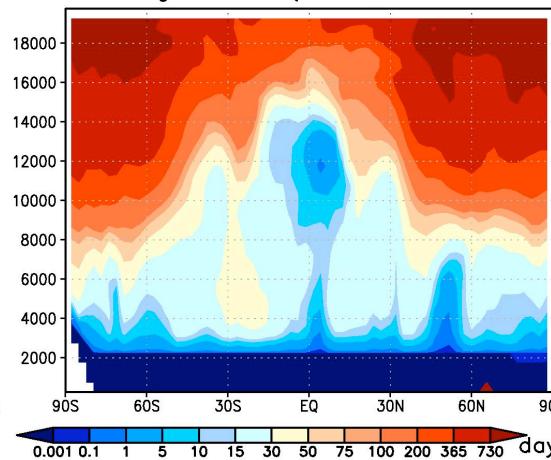
ACTM SF6 (180 E; 30 Jan 2009)

ACTM CO₂ (180 E; 30 Jan 2009)ACTM CH₄ (180 E; 30 Jan 2009)ACTM N₂O (180 E; 30 Jan 2009)

ACTM Radon-222 (180 E; 30 Jan 2009)



ACTM "Age" of air (180 E; 30 Jan 2009)



GEOS-Chem simulations

- GEOS-5 Metfields (provided by GMAO – NASA)
- $2^\circ \times 2.5^\circ$ horiz., 47 vertical levels
- Monthly OH fields (offline)
- Spin-up: CH₄ 4yrs, CO 1 yr

CO EMISSION DETAILS:

- EPA NEI99 Nth Am. (60% decr. Following Hudman et al. 2008)
- EMEP over Europe
- Streets 2006 + Seas. Variation over Asia
- CAC over Canada
- BRAVO over Mexico
- EDGAR 3.2FT2000 elsewhere
- GFED2 for all biomass burning ('08 emis. estim. for '09)
- All anthropogenic emis. incr. by 19% and all biomass burn. By 11% to account for oxidation of VOCs that are not carried in lin. simulation

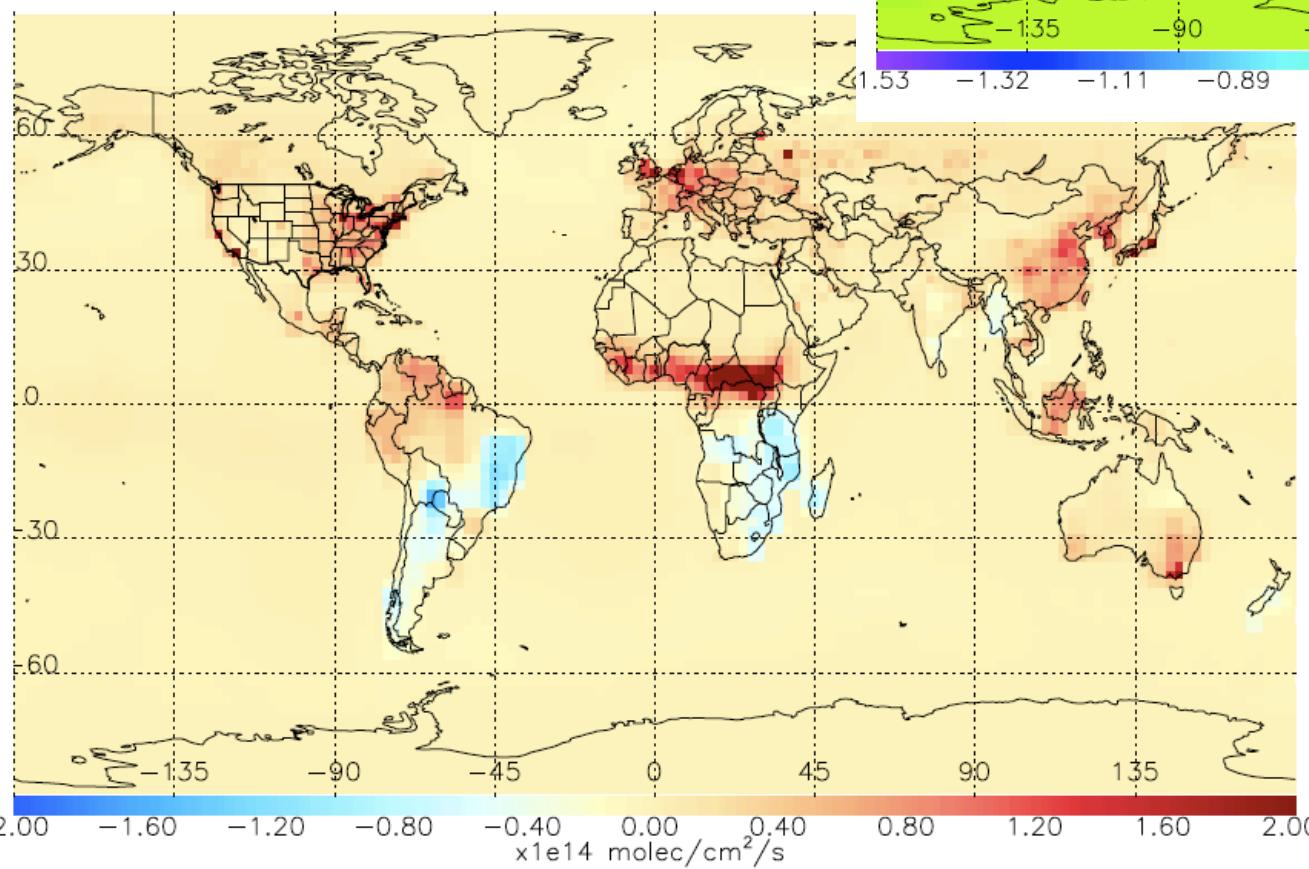
*Daniel Jacob
Christopher Pickett-Heaps
Huiqin Wang
Jenny Fisher*

CH₄ EMISSION DETAILS:

- Anthropogenic emissions from EDGAR 3.2FT2000
- Biomass Burning (GFED2, '09 replicated from previous years)
- Wetlands: Internal bottom-up emissions scheme (Kaplan et al. 2002, Drevet et al. in prep.)
- Annual emissions (anthropogenic, termites)
- Seasonal emissions (wetlands, bio. burning, rice cultivation)

200901 CO2oc

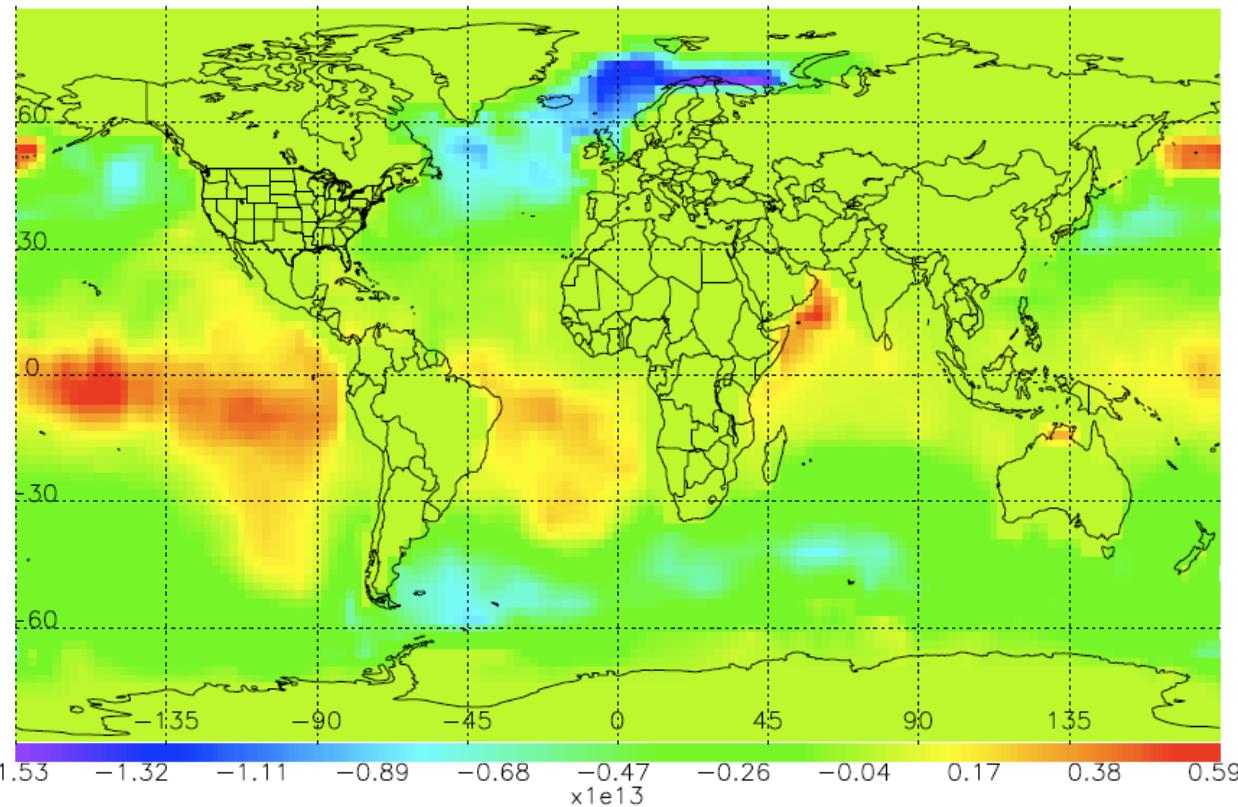
GEOS-CHEM CO₂ surface fluxes, January 2009 (Huiqun Wang, Harvard University)



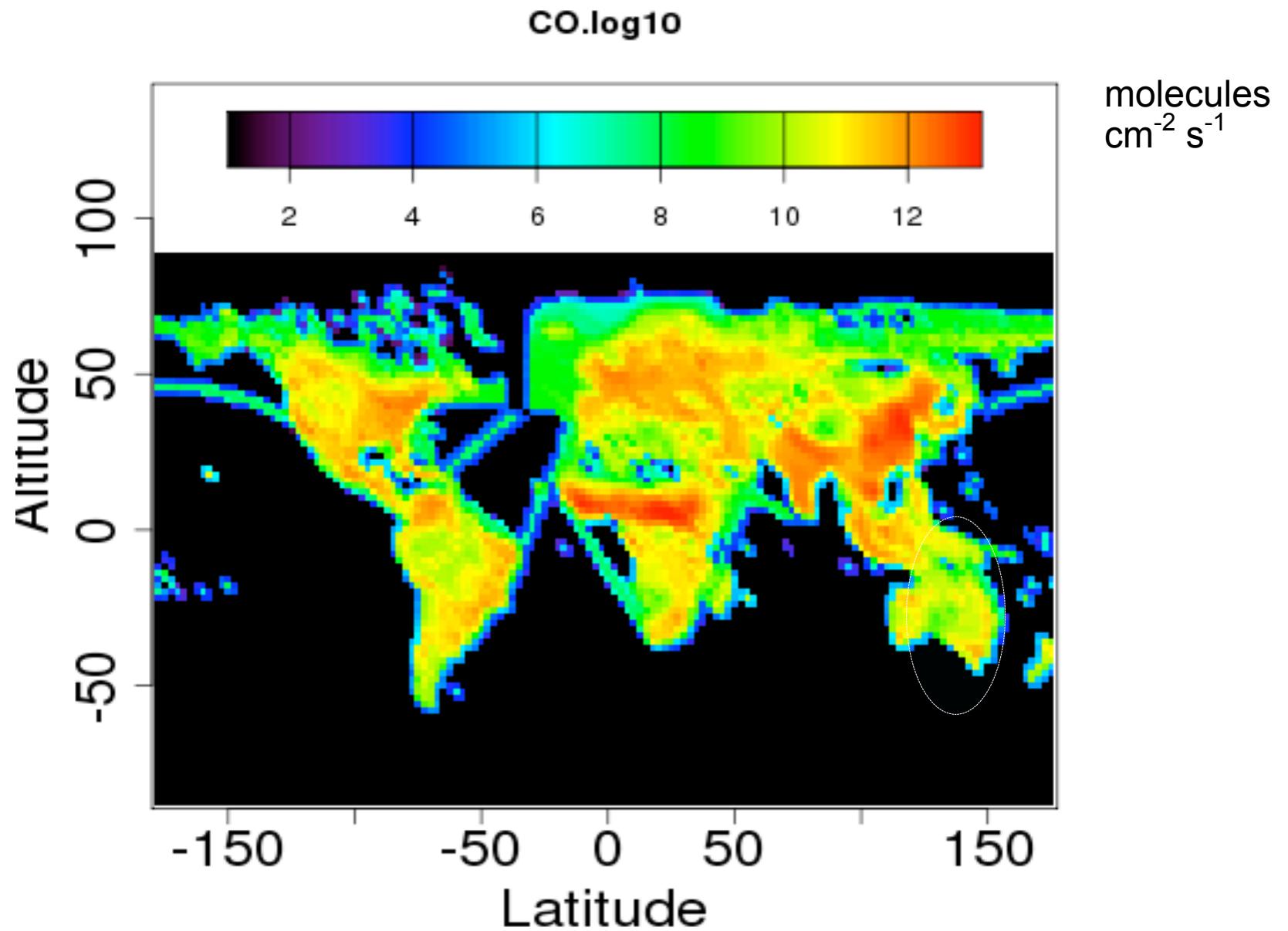
Ocean fluxes (10^{13} cm⁻²s⁻¹)

$$1 \times 10^{13} = 0.16 \text{ } \mu\text{mole m}^{-2} \text{ s}^{-1}$$

Land fluxes (10^{14} cm⁻²s⁻¹)

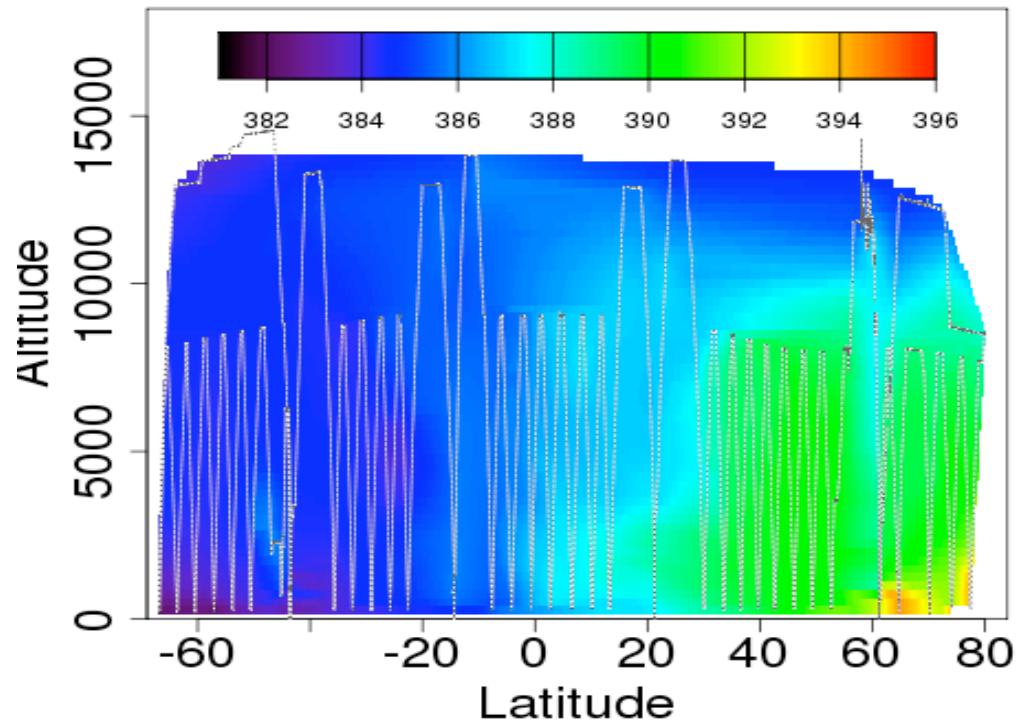


CO Emission Flux for January from GEOS-CHEM



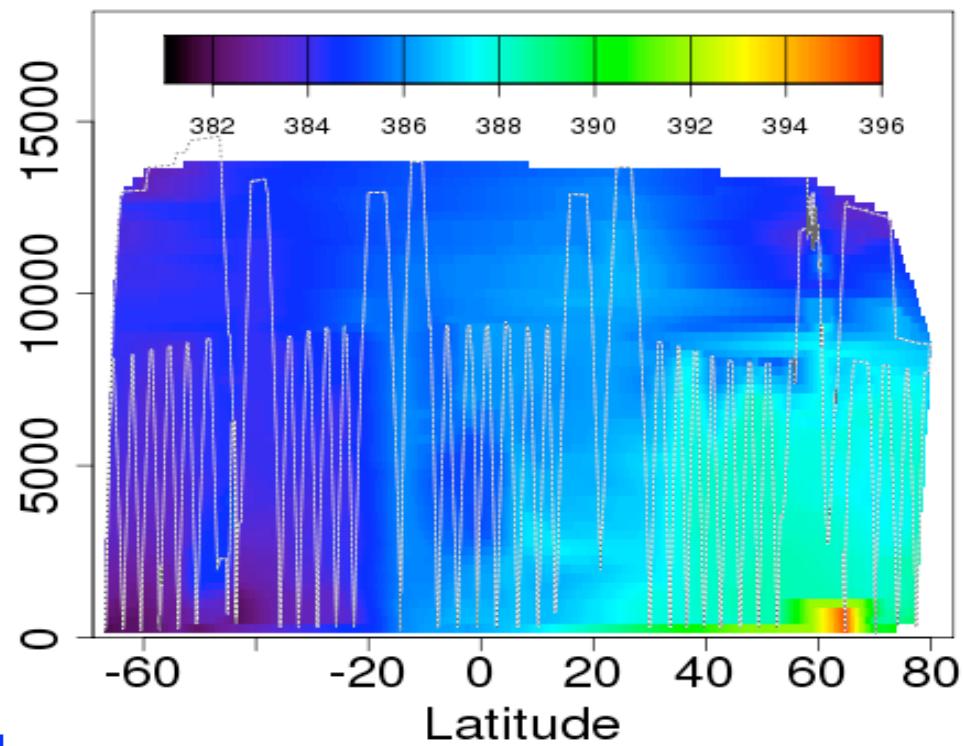
ACTM

CO₂.ppm.



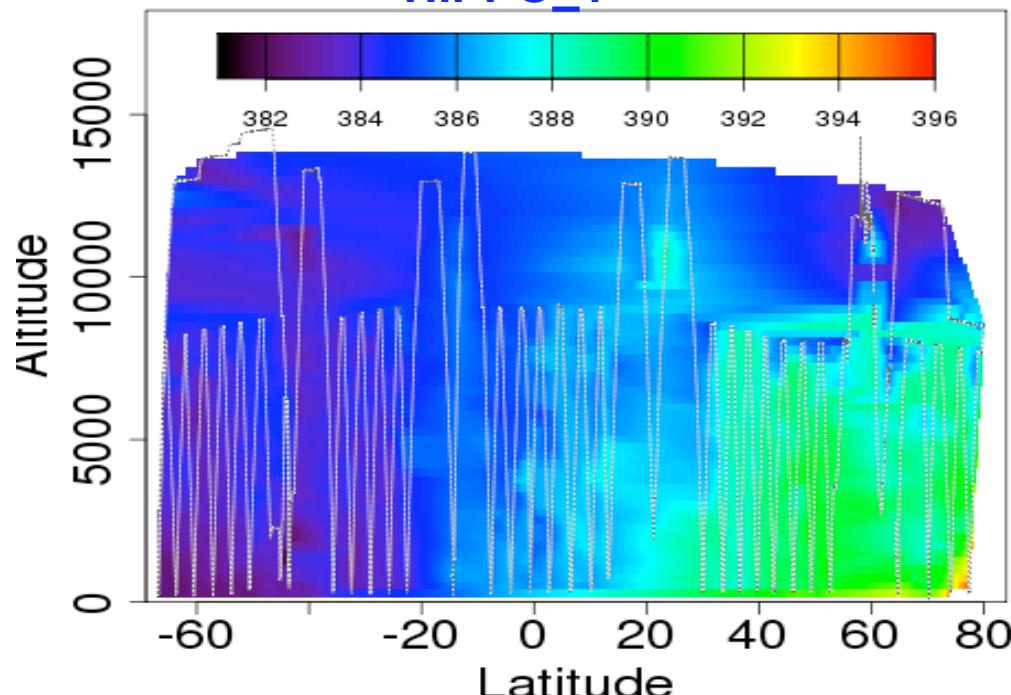
GEOS CHEM

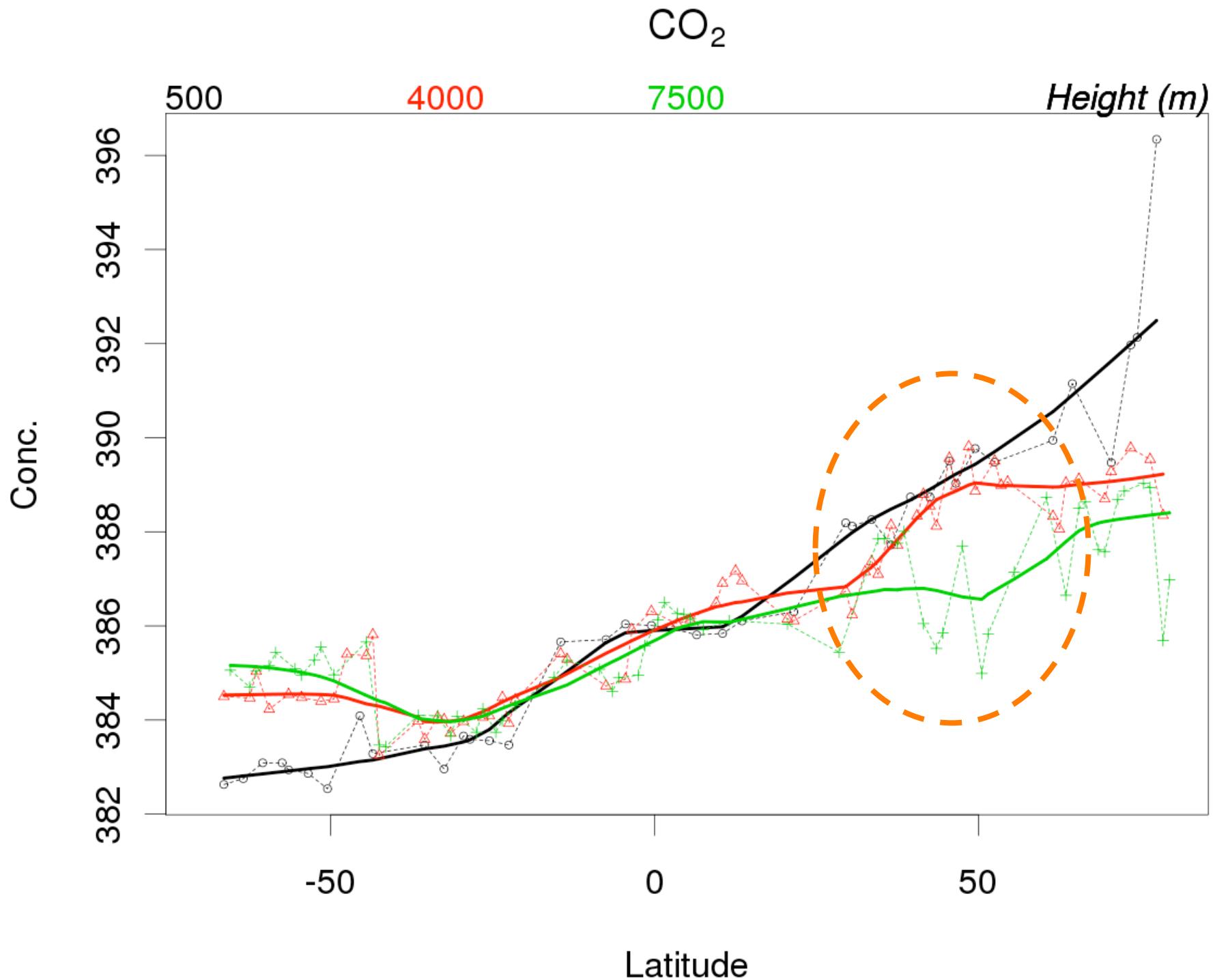
CO₂

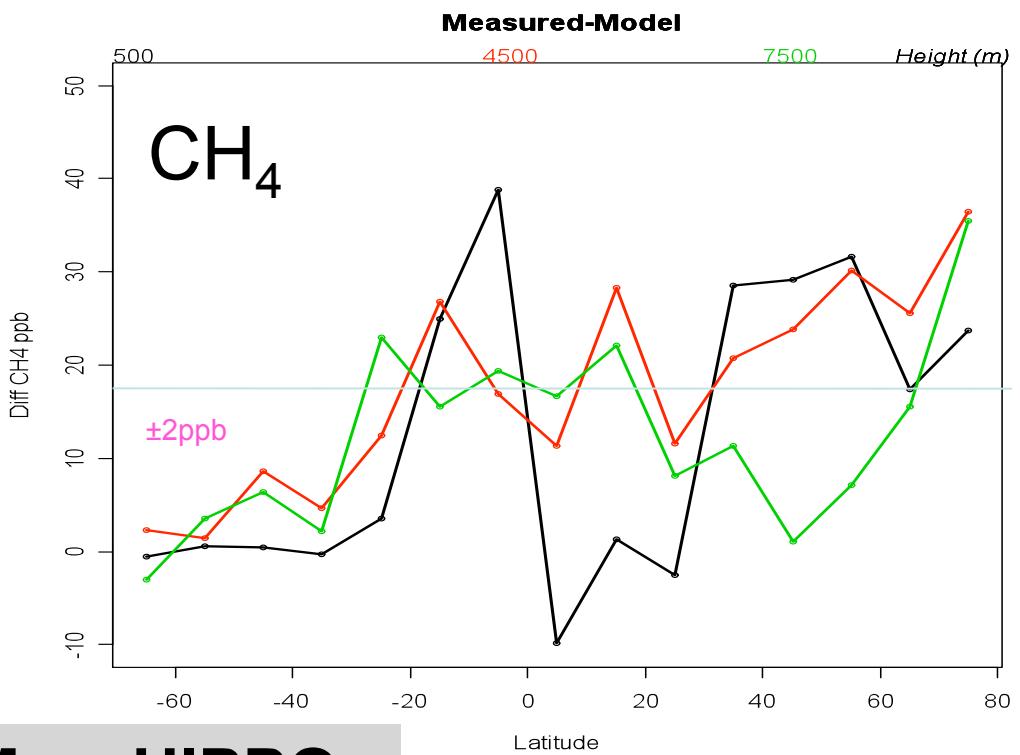
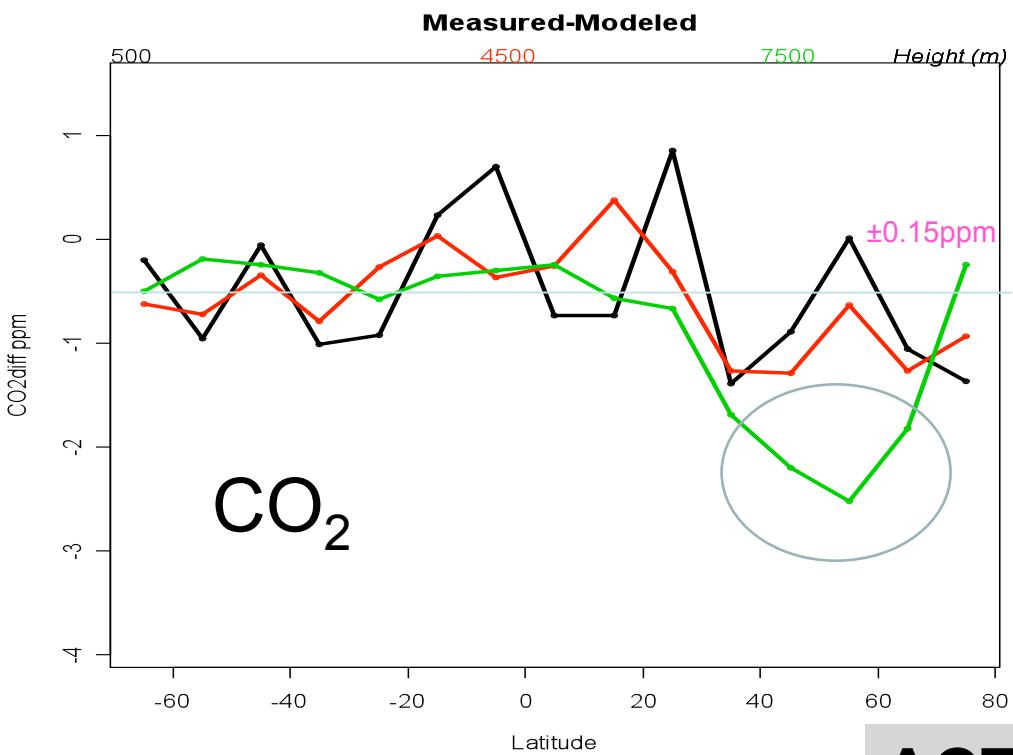


HIPPO_1

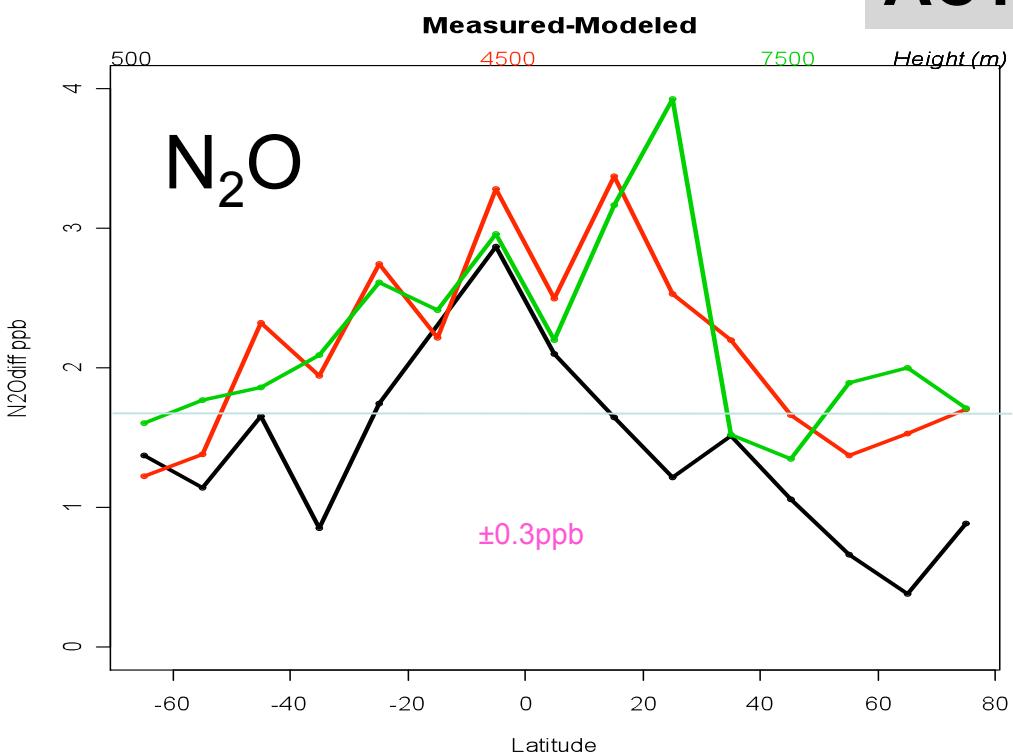
CO₂

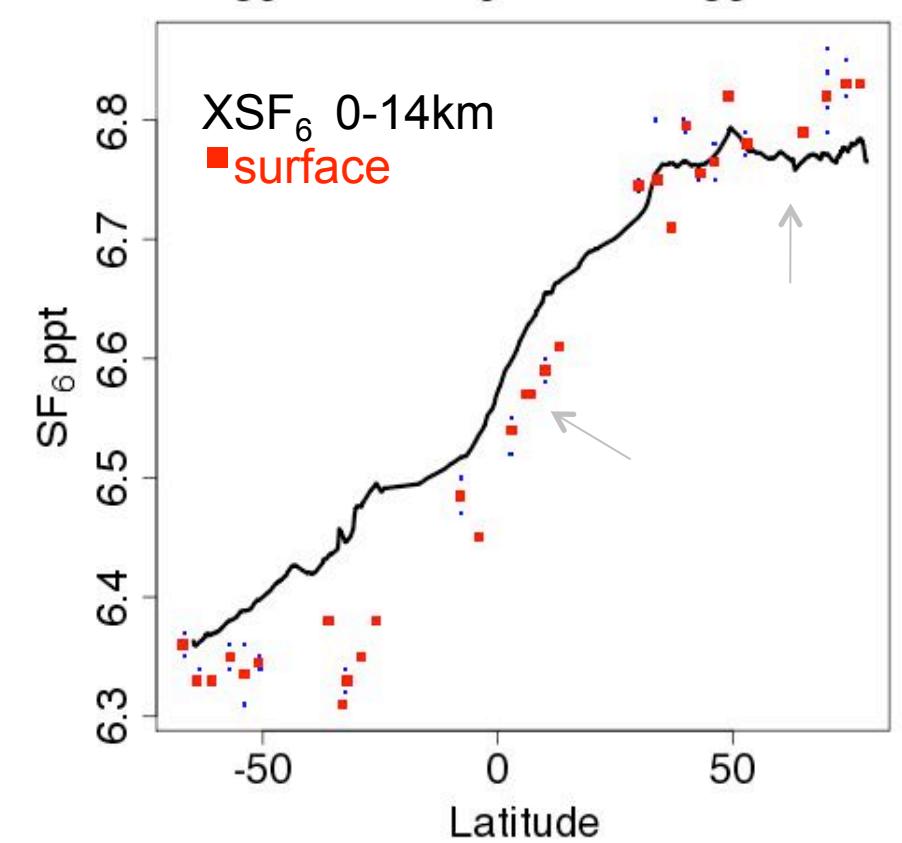
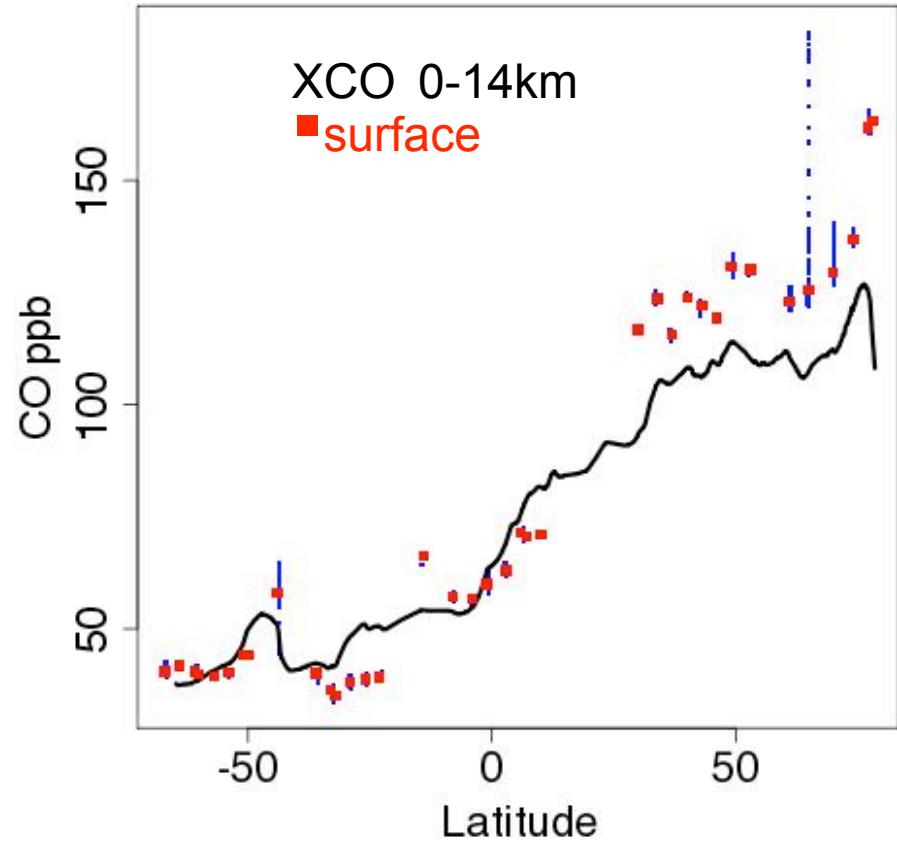
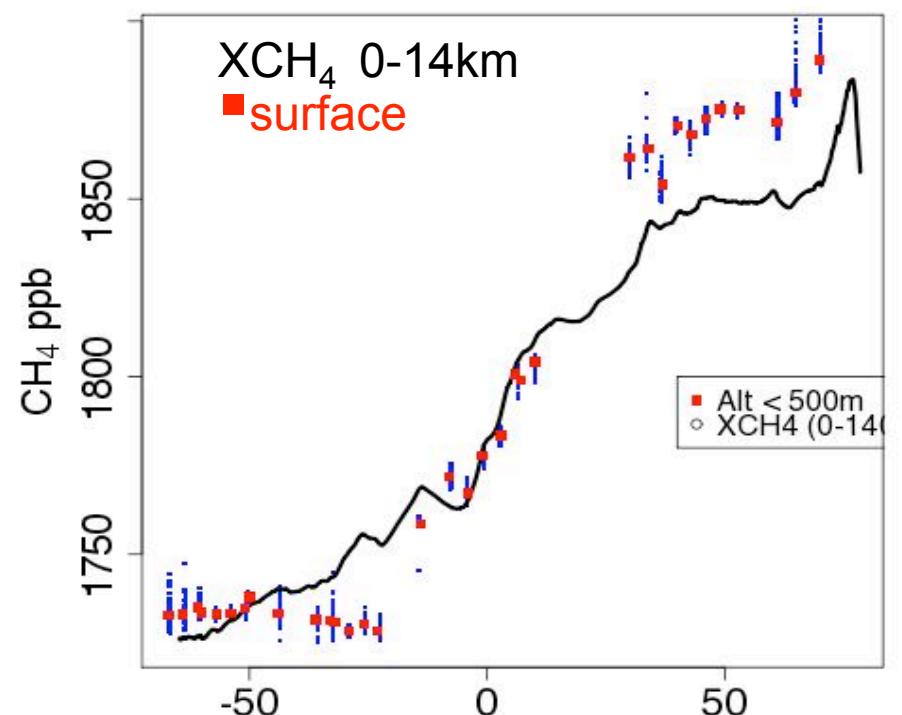
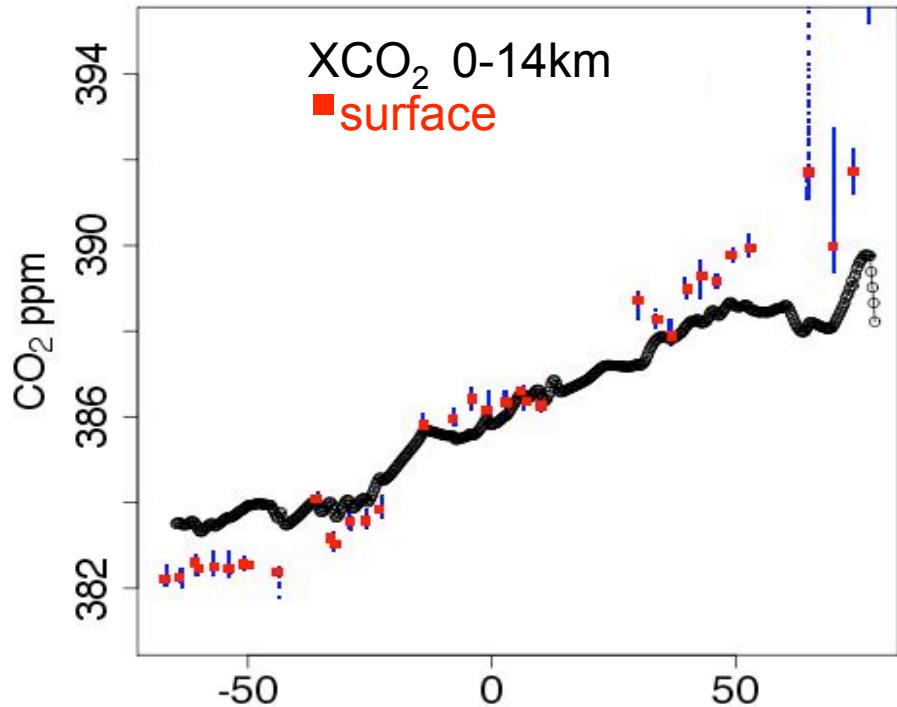




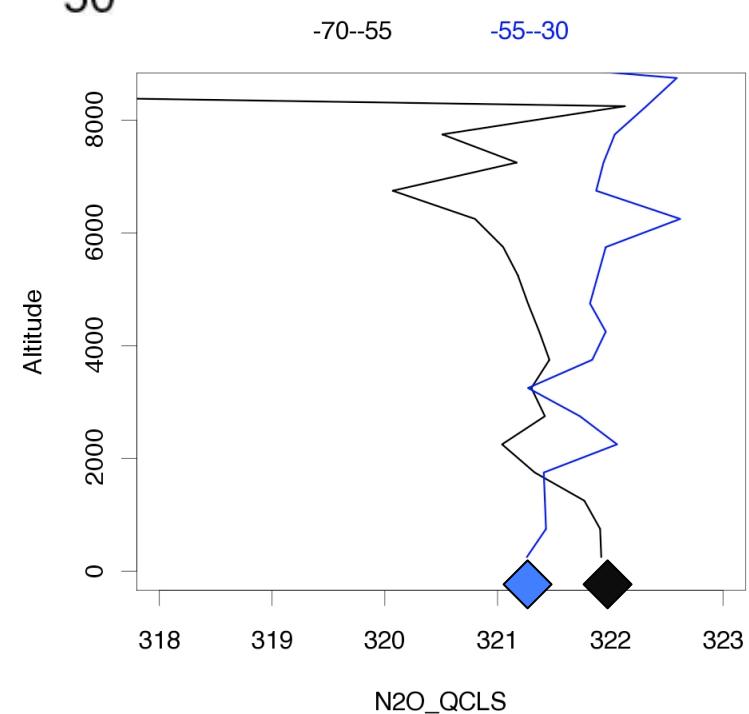
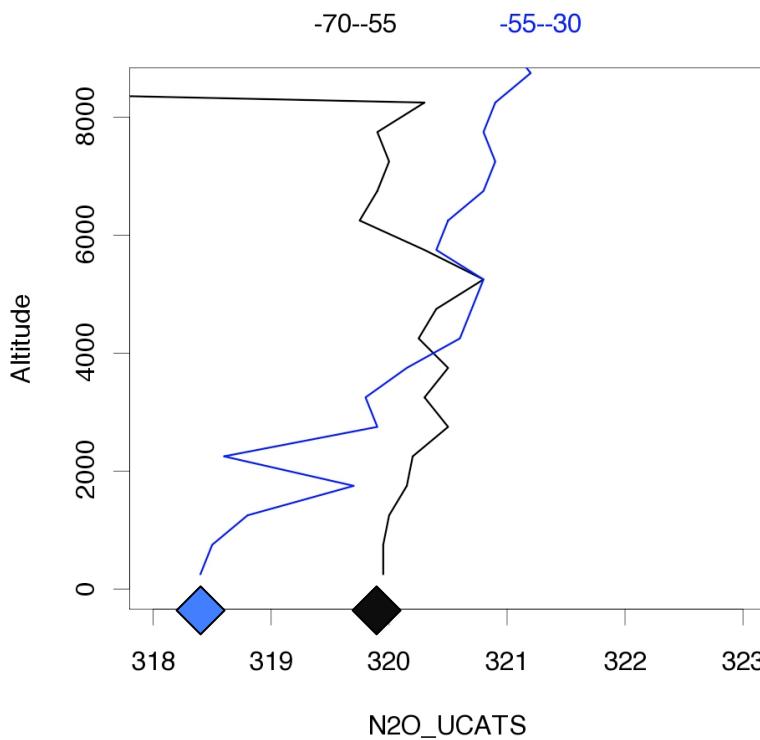
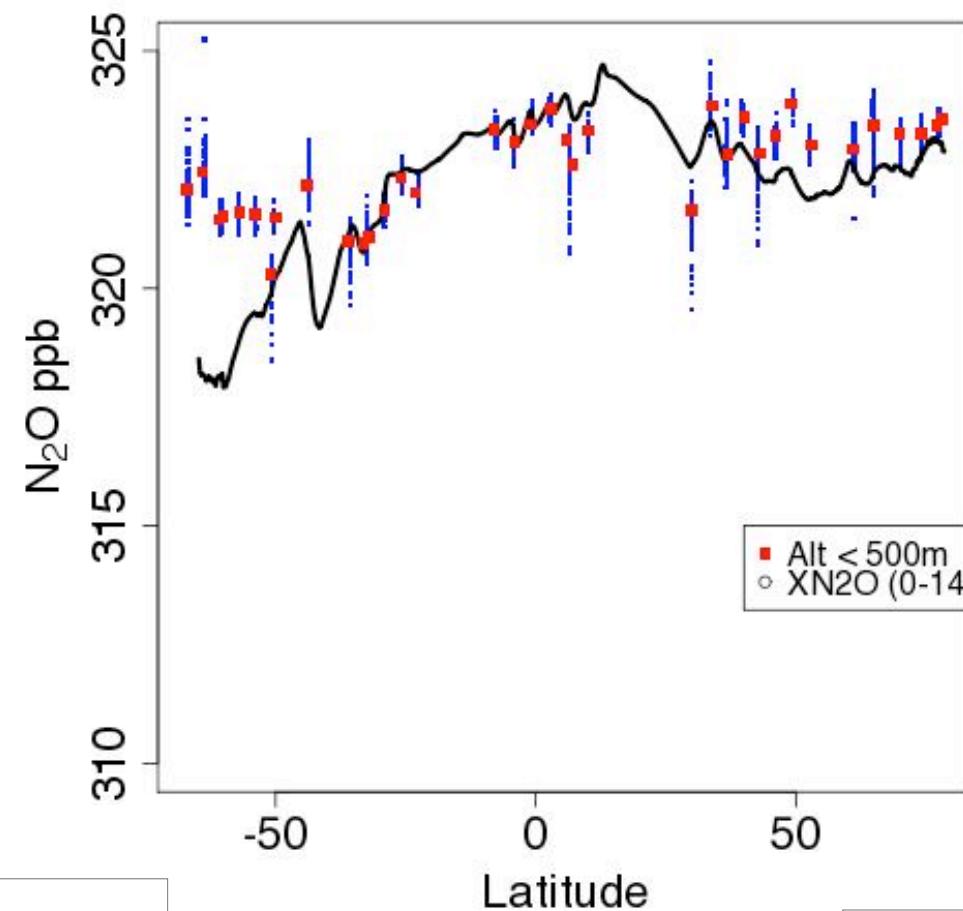


ACTM vs HIPPO





Evidence for a strong N₂O source in the Southern Ocean ?



SF₆ UCATS HIPPO_1 January 2009

Rts 3 4 5 6 7

15000

6.0

6.2

6.4

6.6

6.8

7.0

10000

5000

0

-60

-40

-20

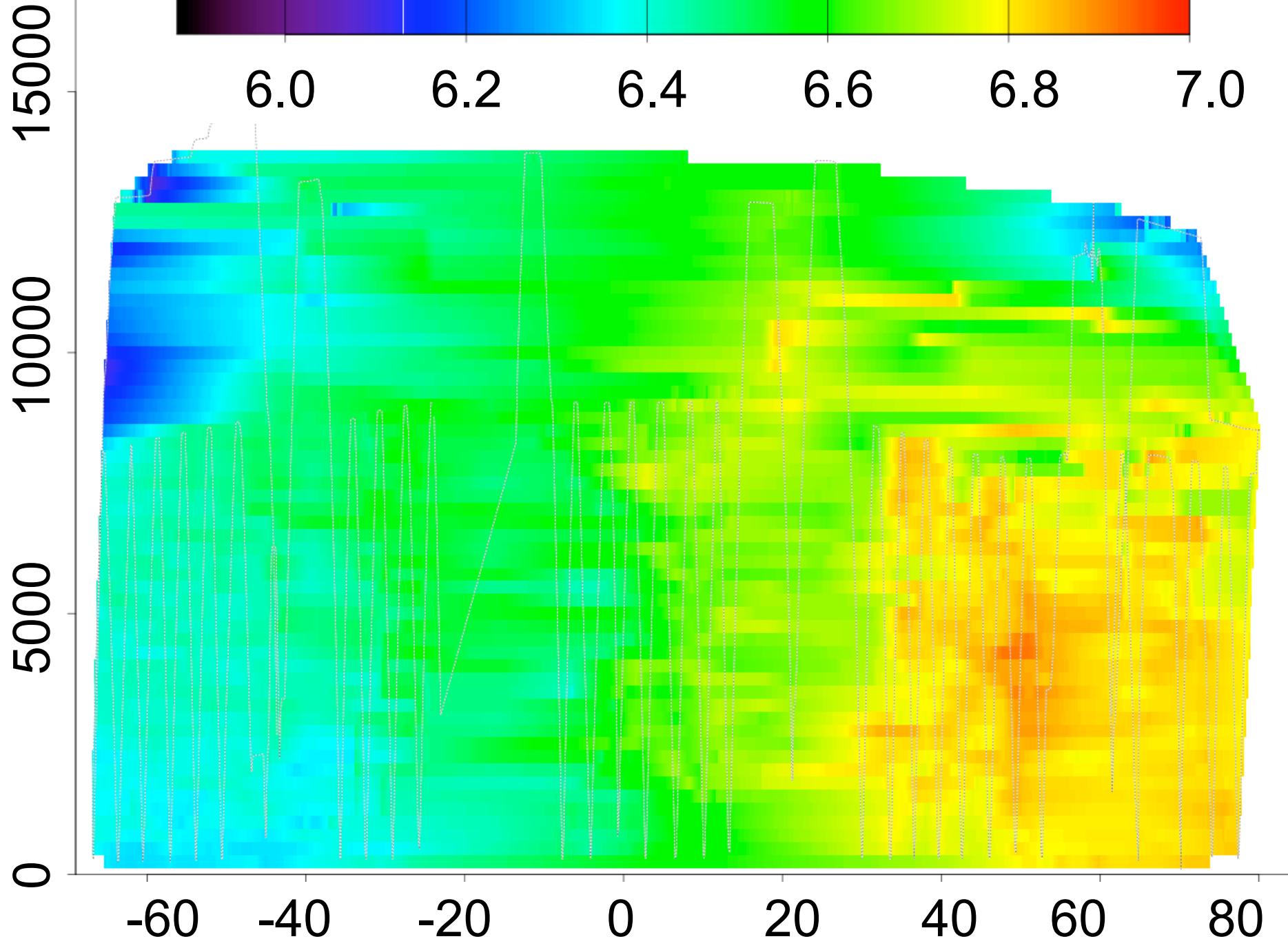
0

20

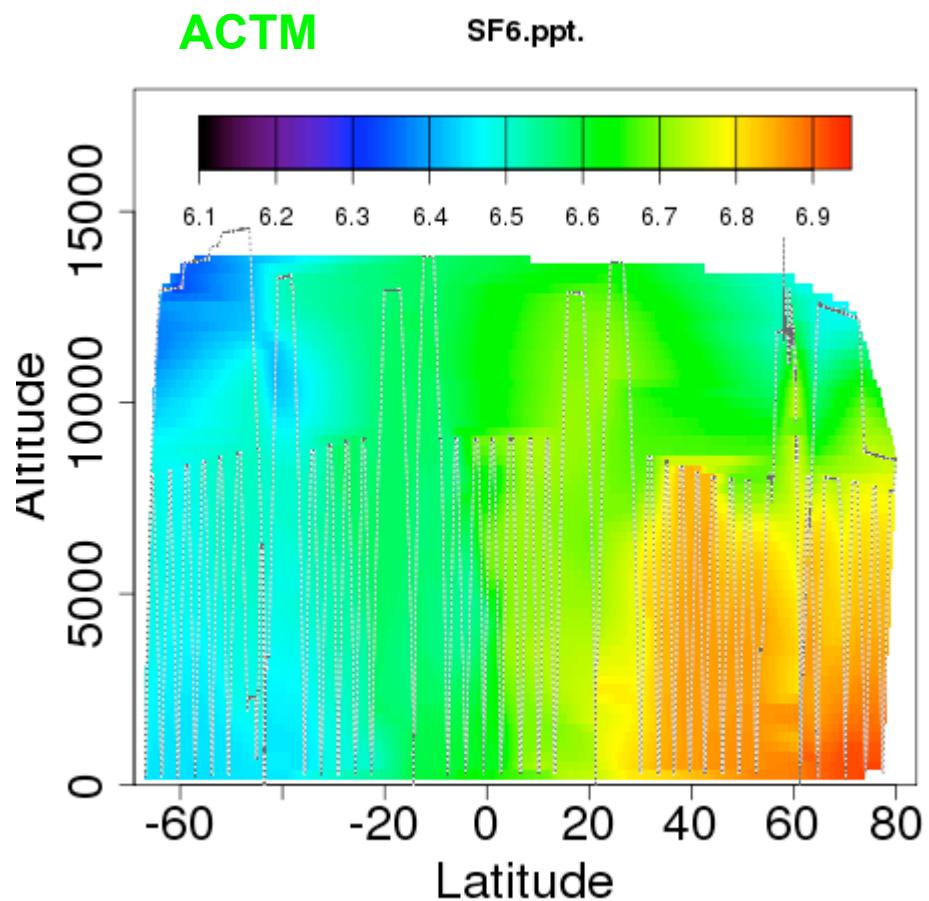
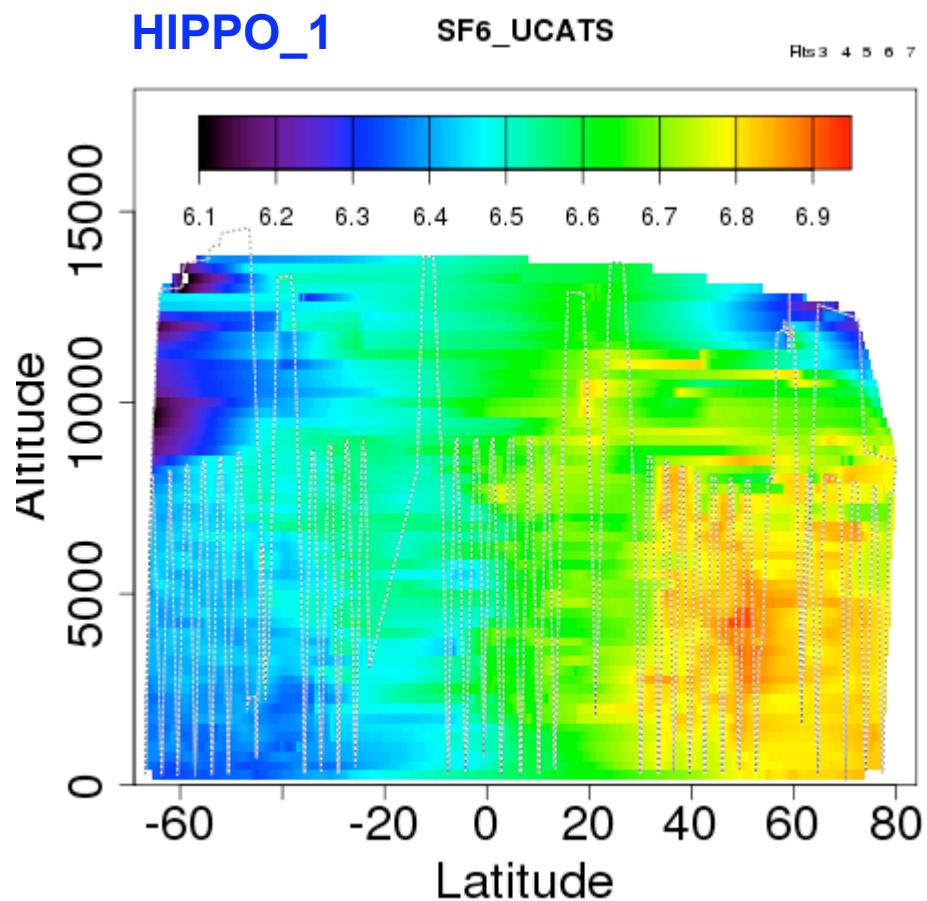
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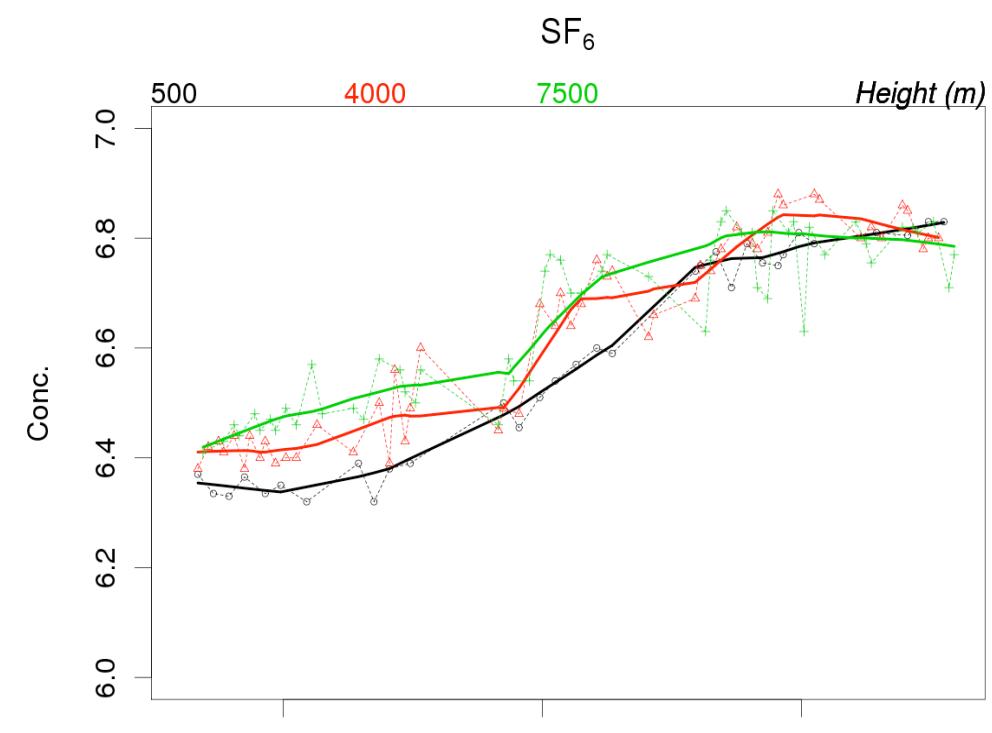
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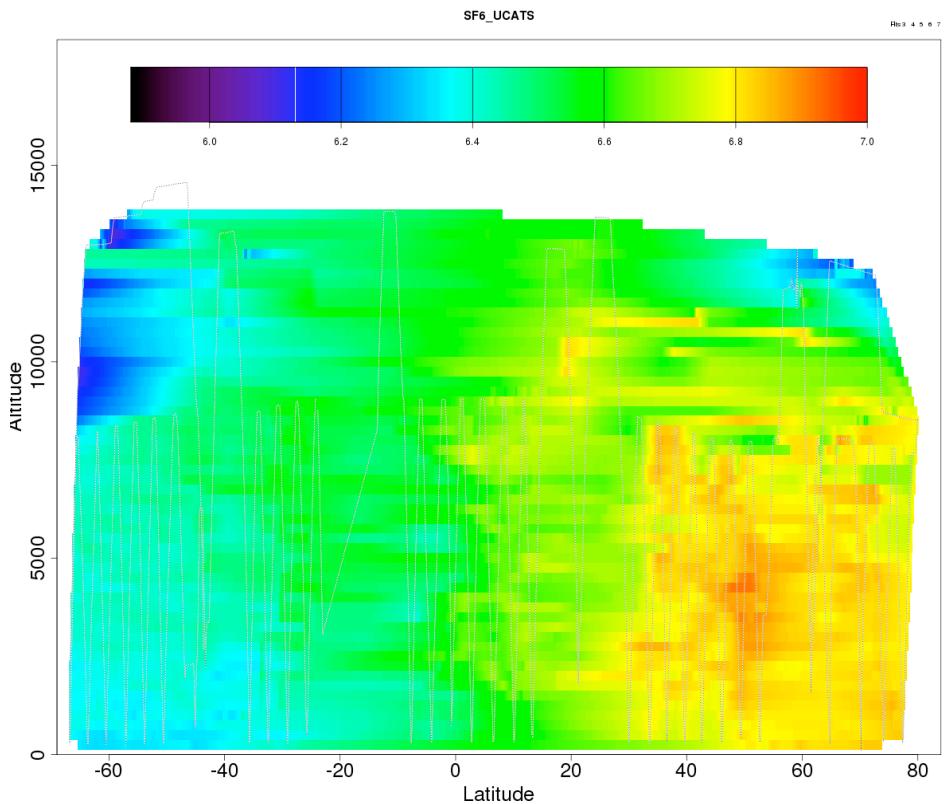
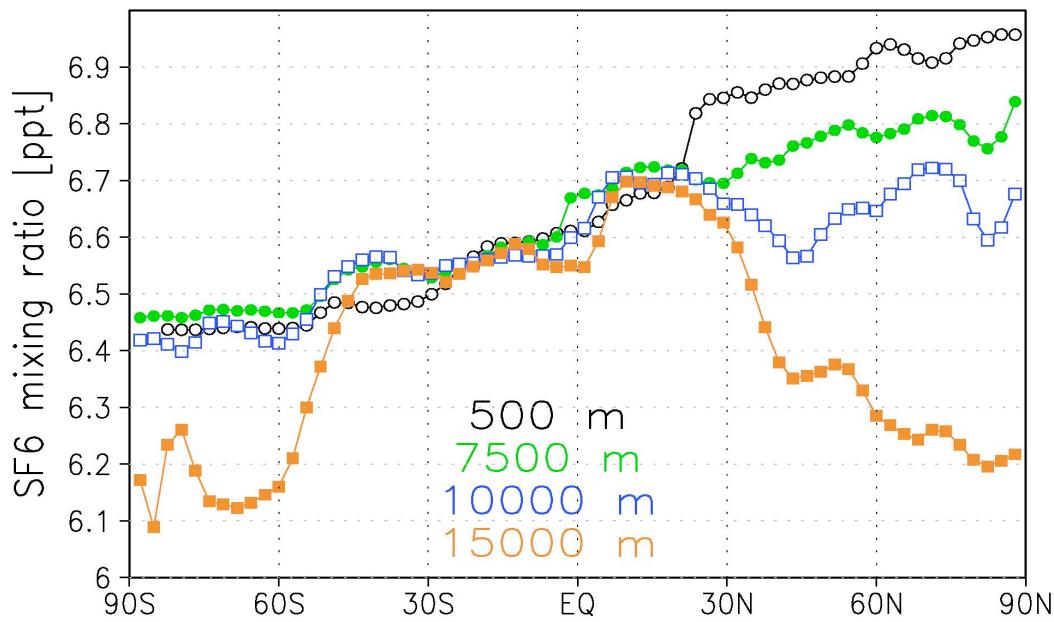
SF₆



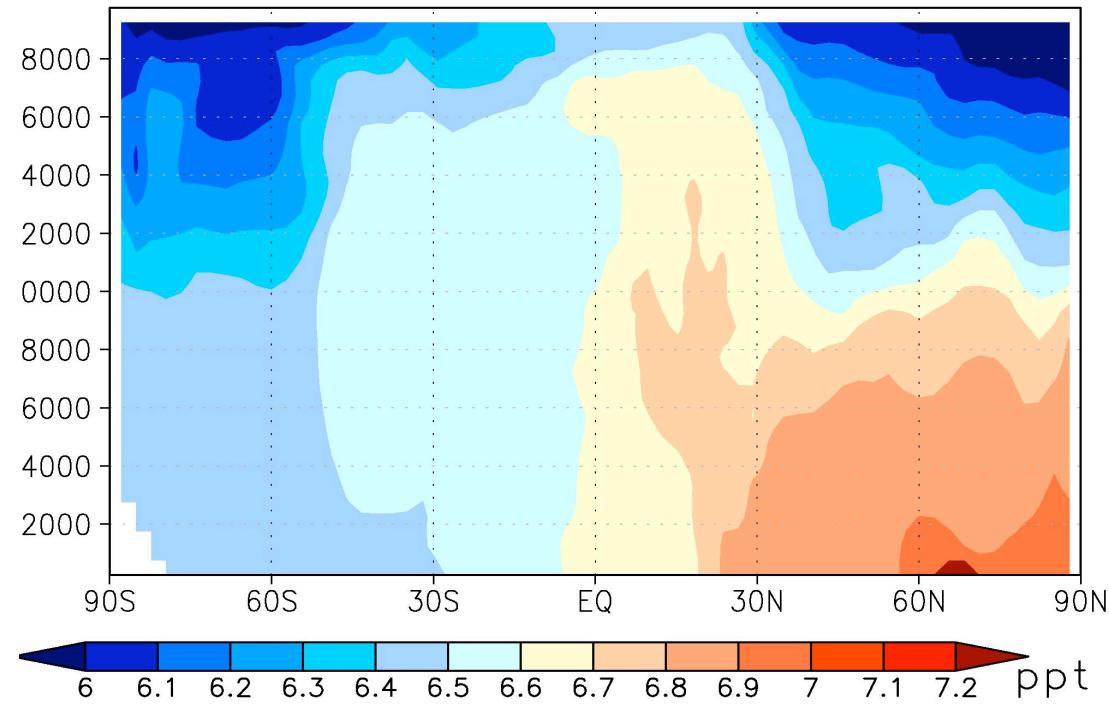
Asian plume, warm conveyor belt; age of air in So. Ocean (!!)



ACTM SF6 (180 E; 09 Jan 2009)



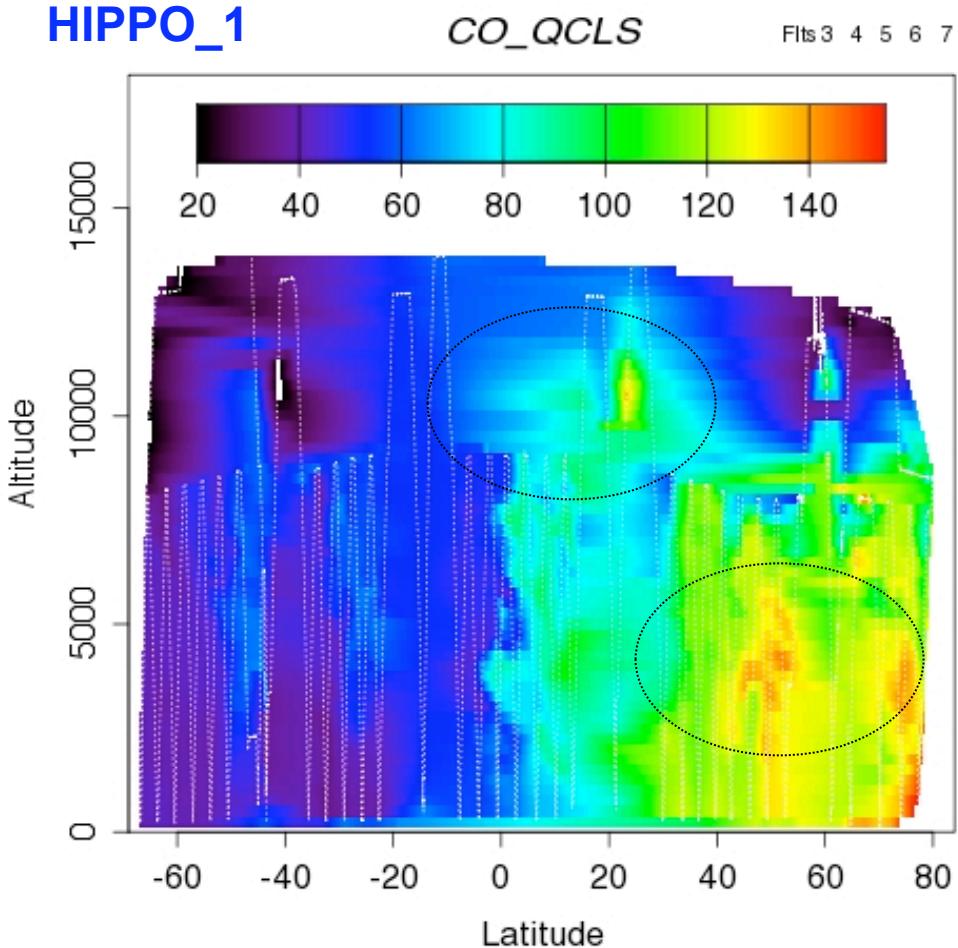
ACTM SF6 (180 E; 09 Jan 2009)



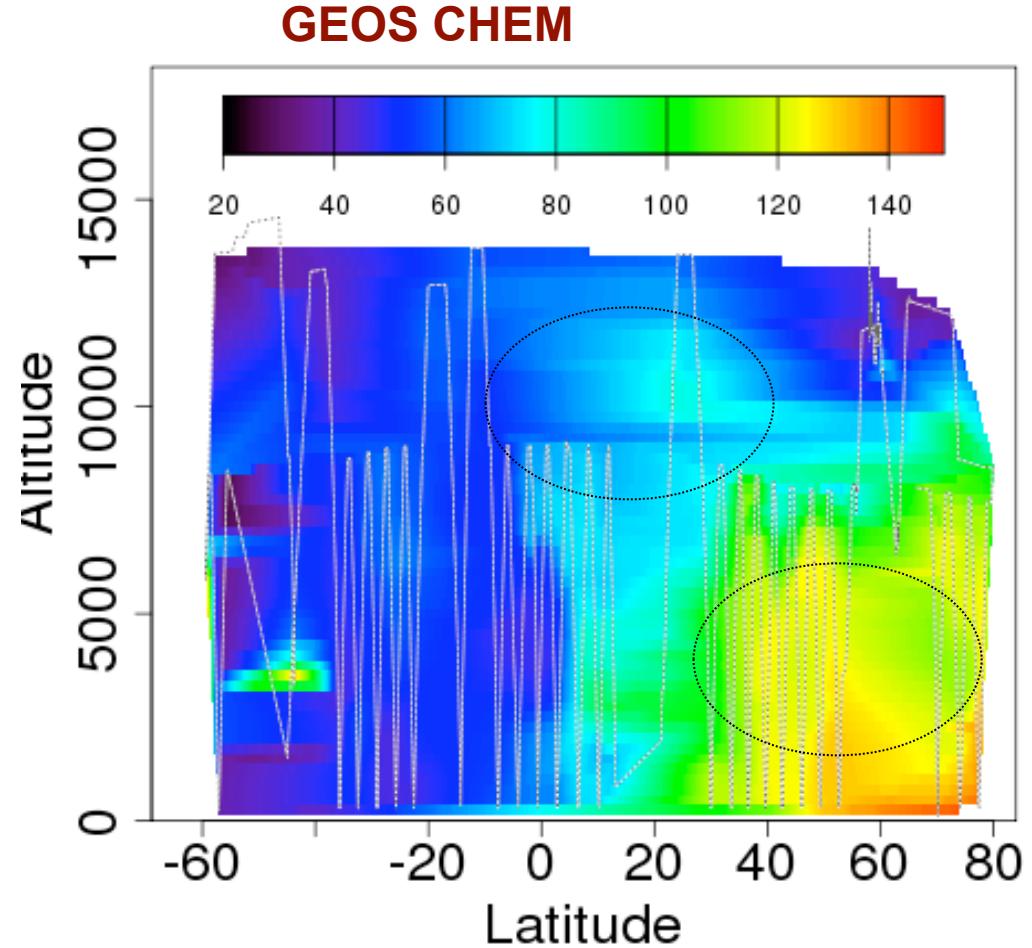
HIPPO_1

CO_QCLS

Fits 3 4 5 6 7



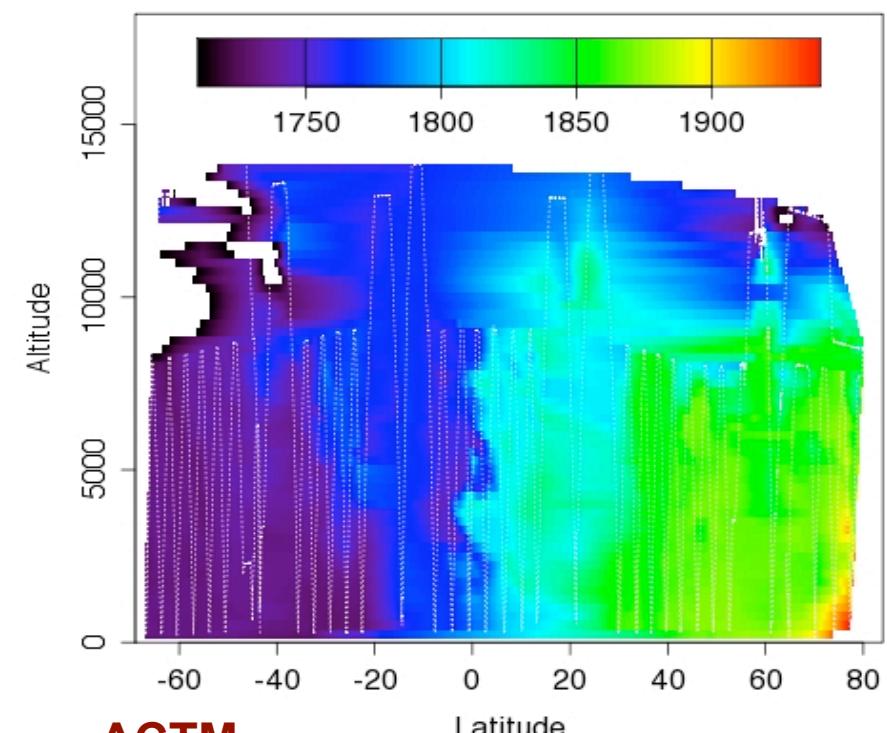
GEOS CHEM



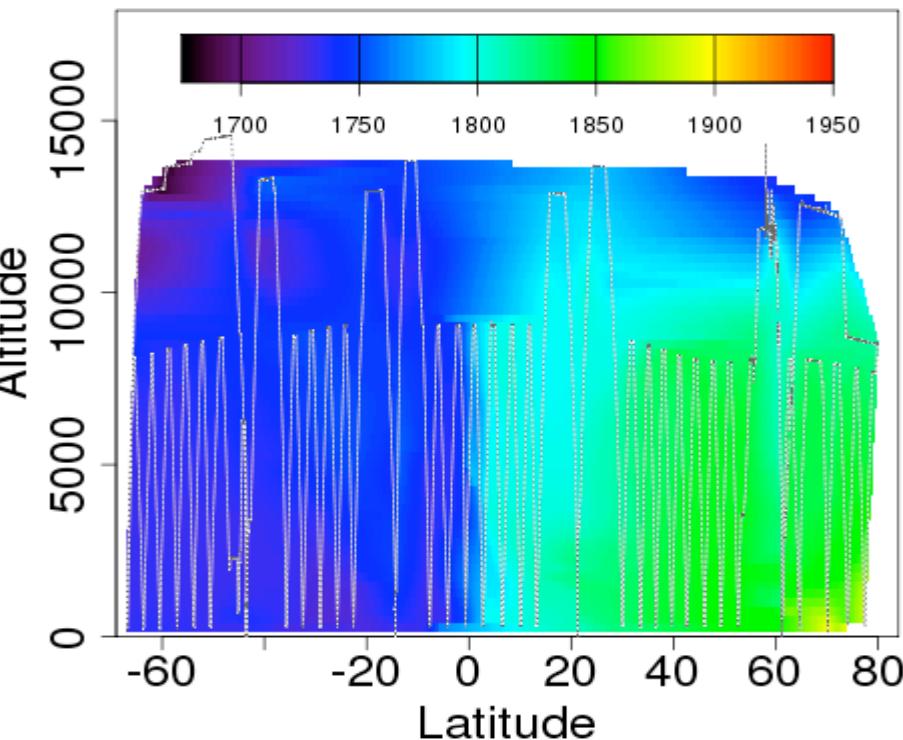
CO

CH₄_QCLS

Flts 3 4 5 6 7

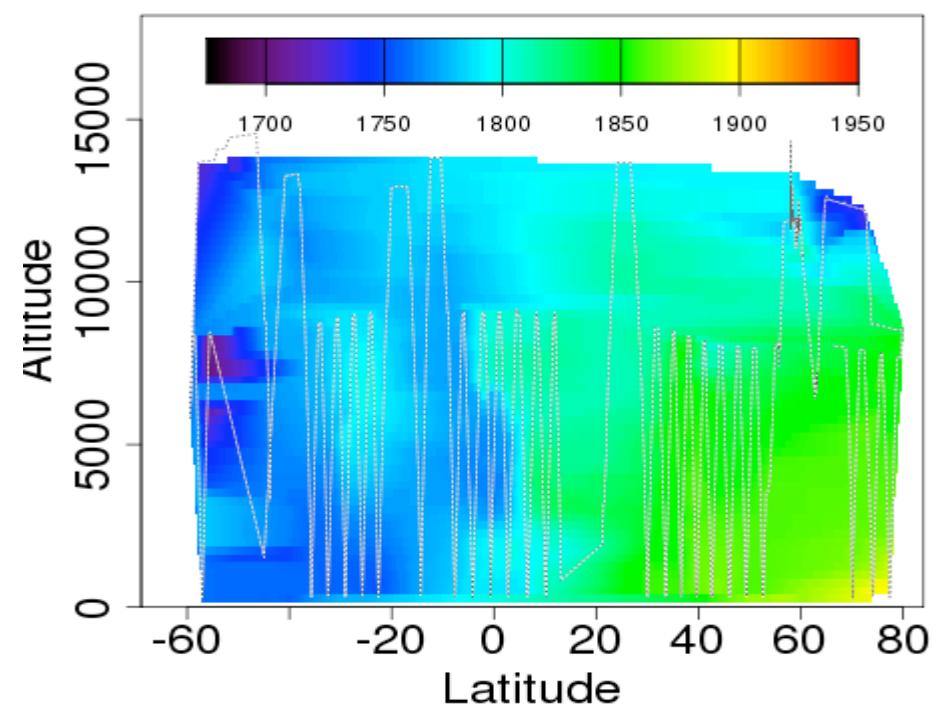


ACTM

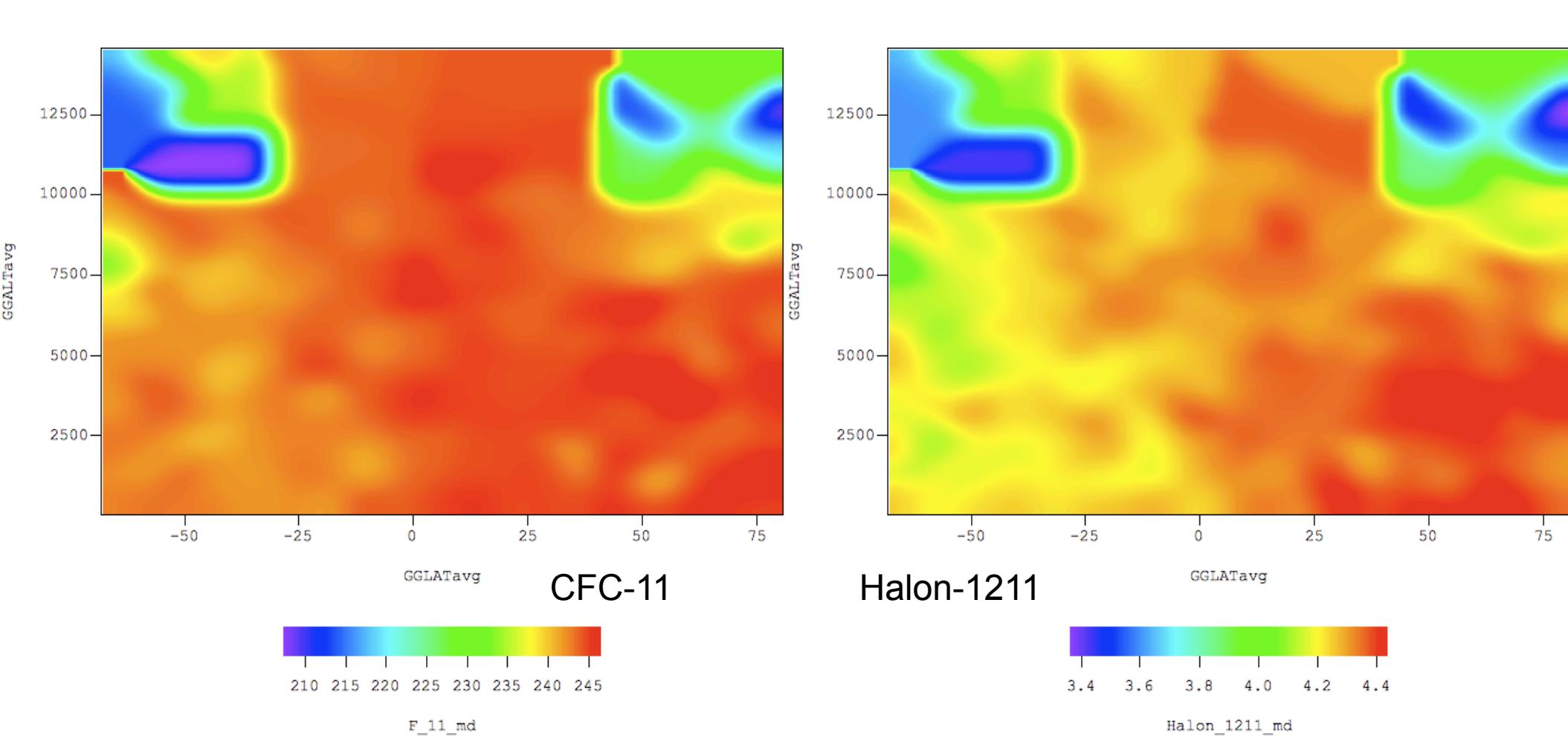


GEOS CHEM

MODEL_DATA

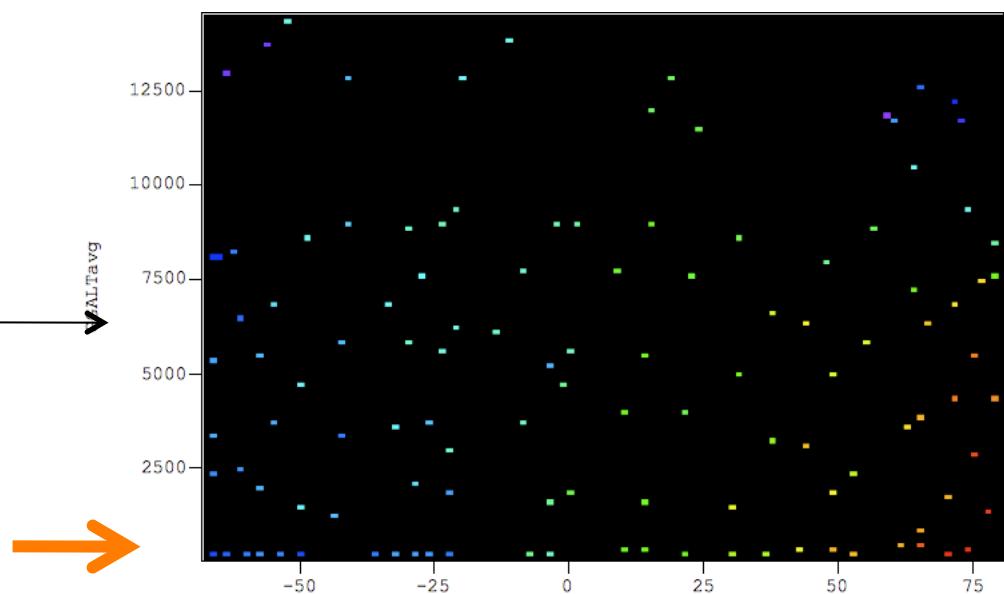


CH₄

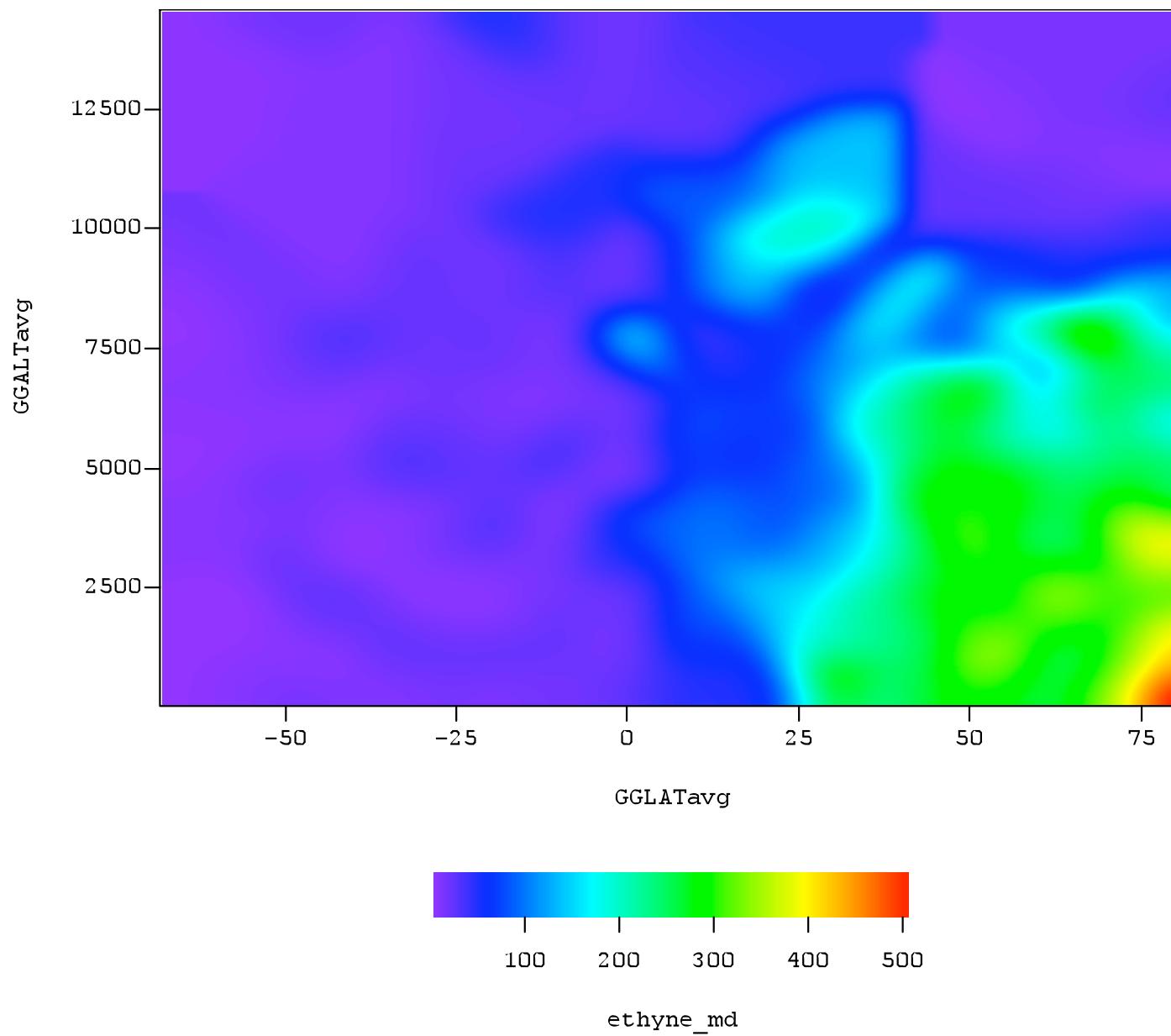


Whole-Air Sampling NWAS /
AWAS (E. Atlas, S. Montzka)

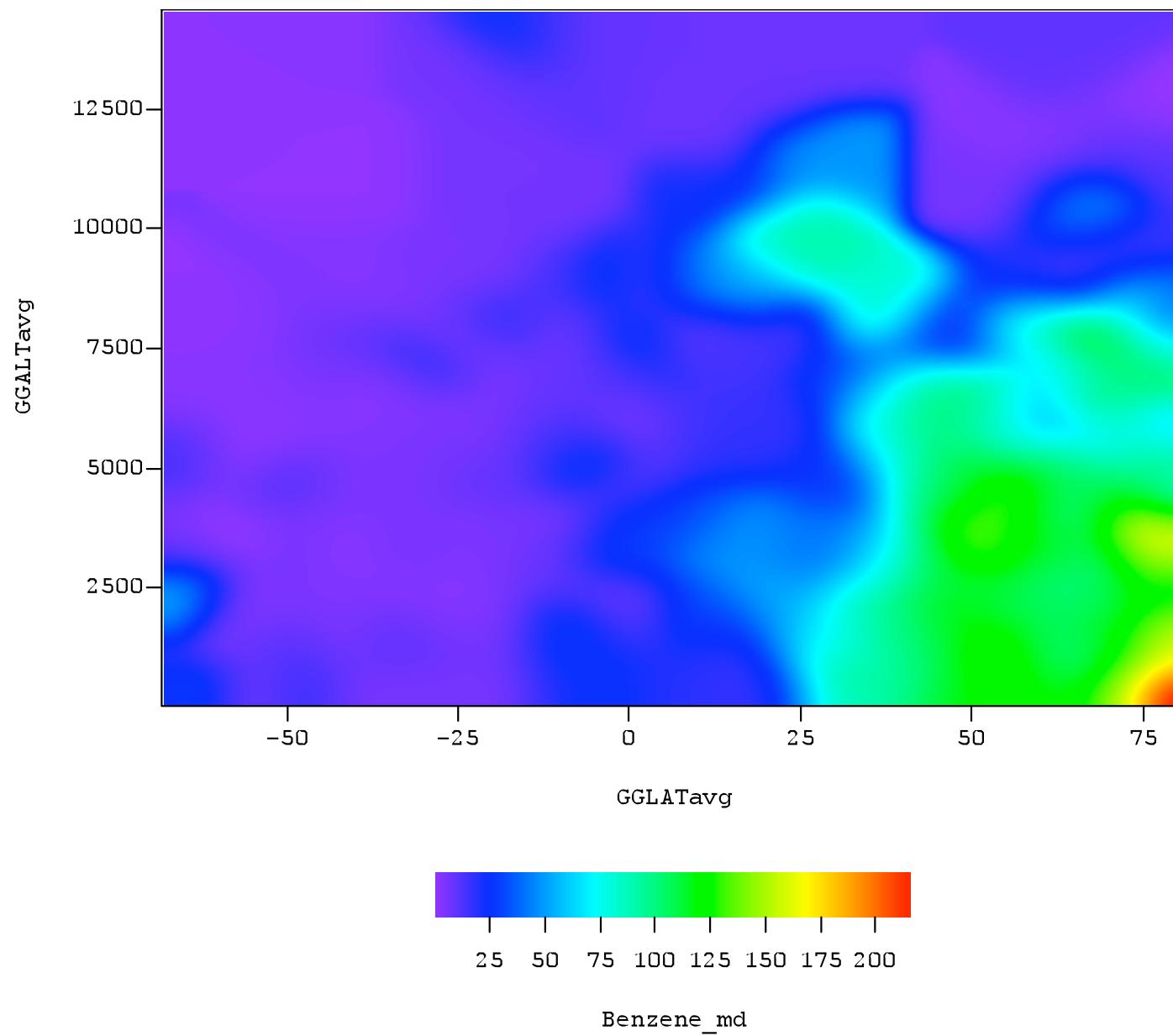
Mid-Pacific Sample coverage →



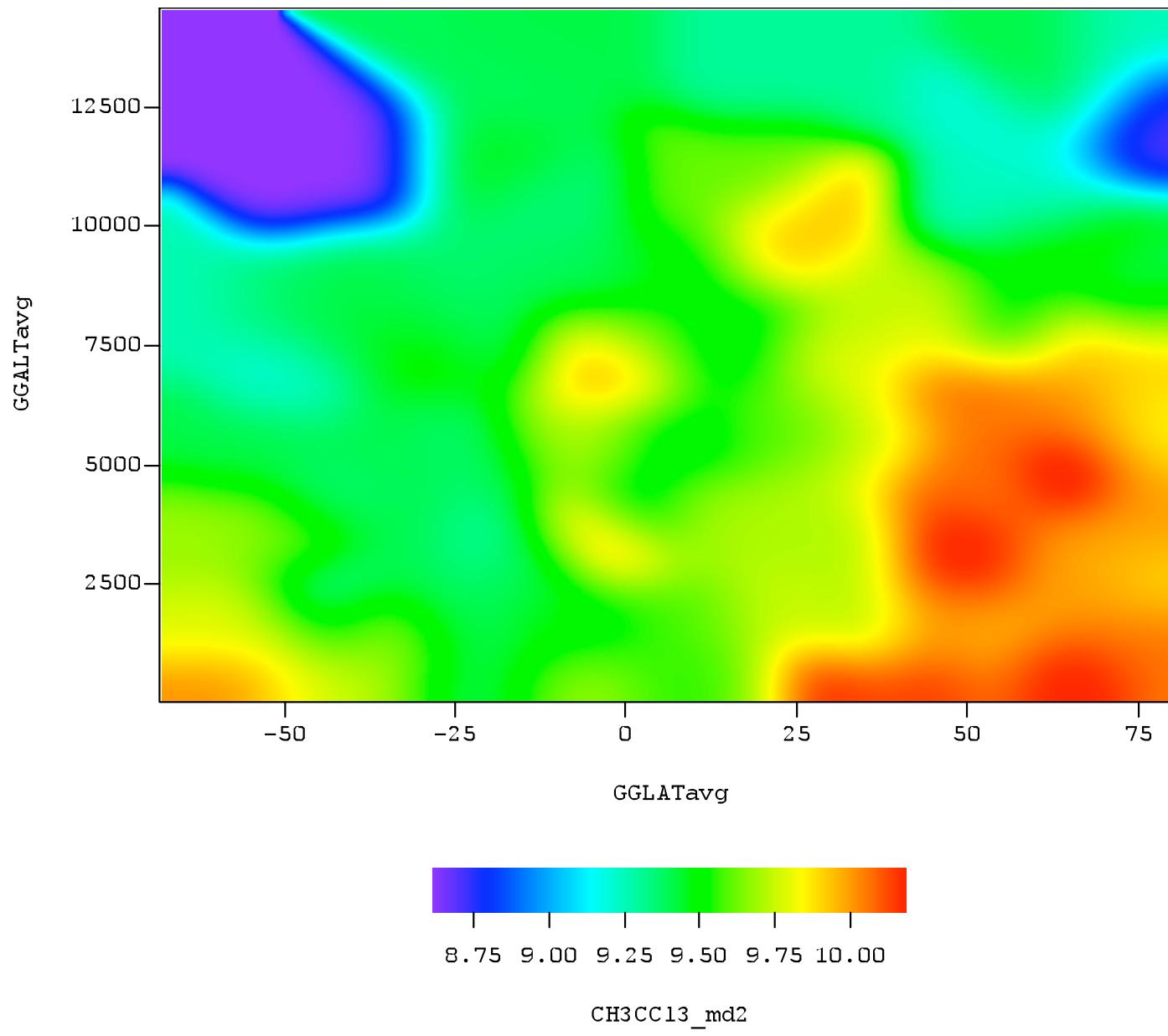
Ethyne



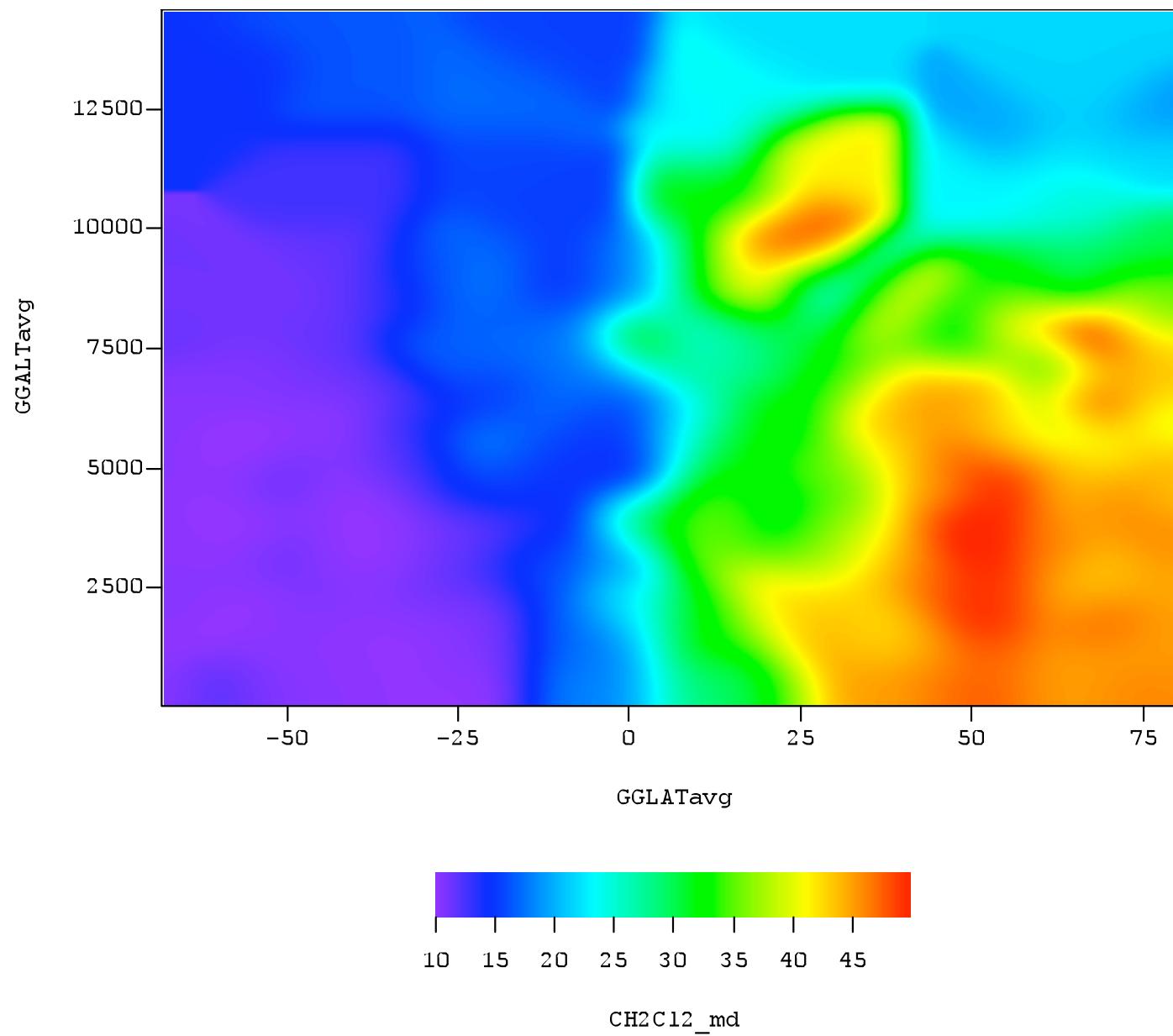
Benzene



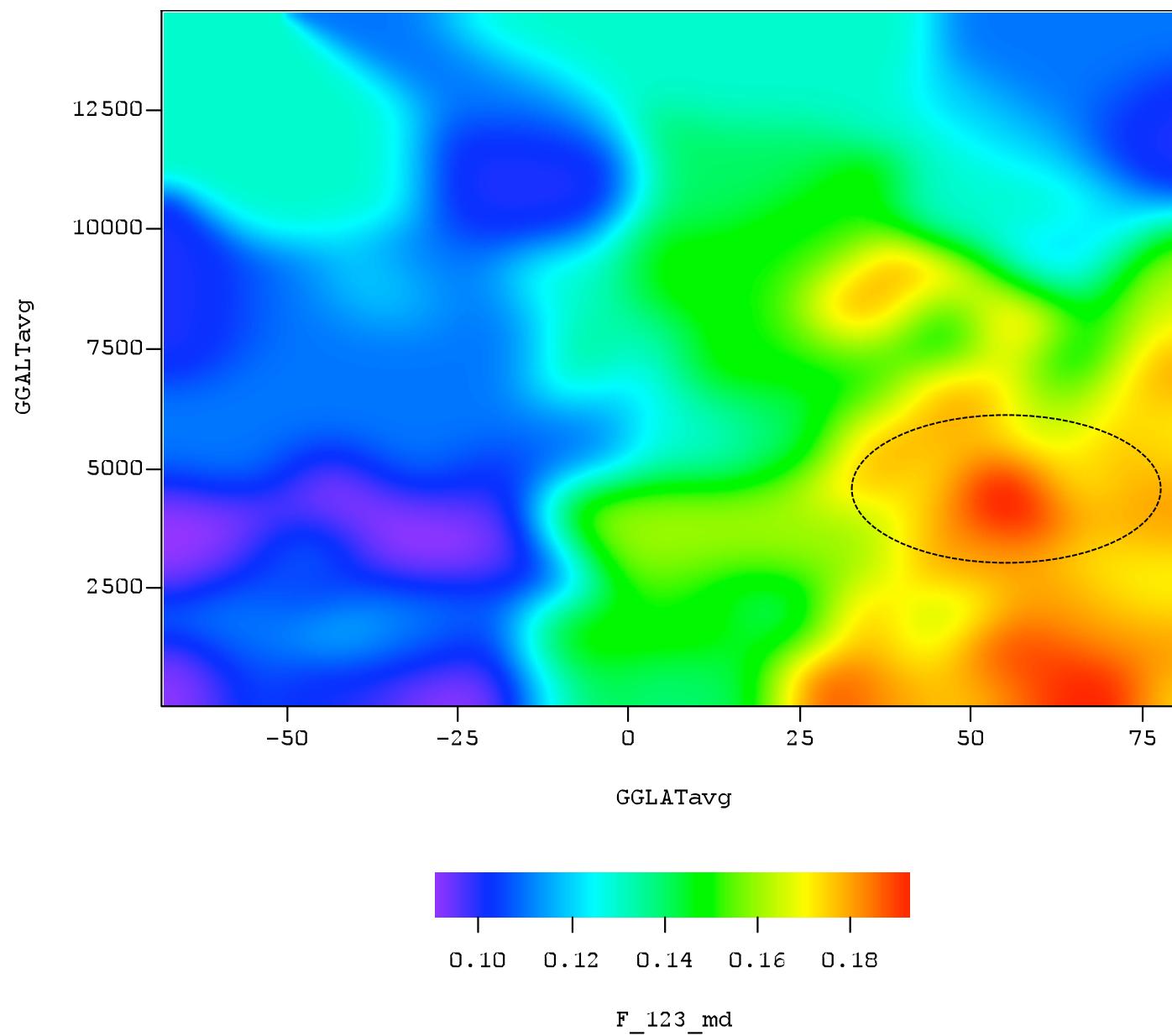
Methyl chloroform



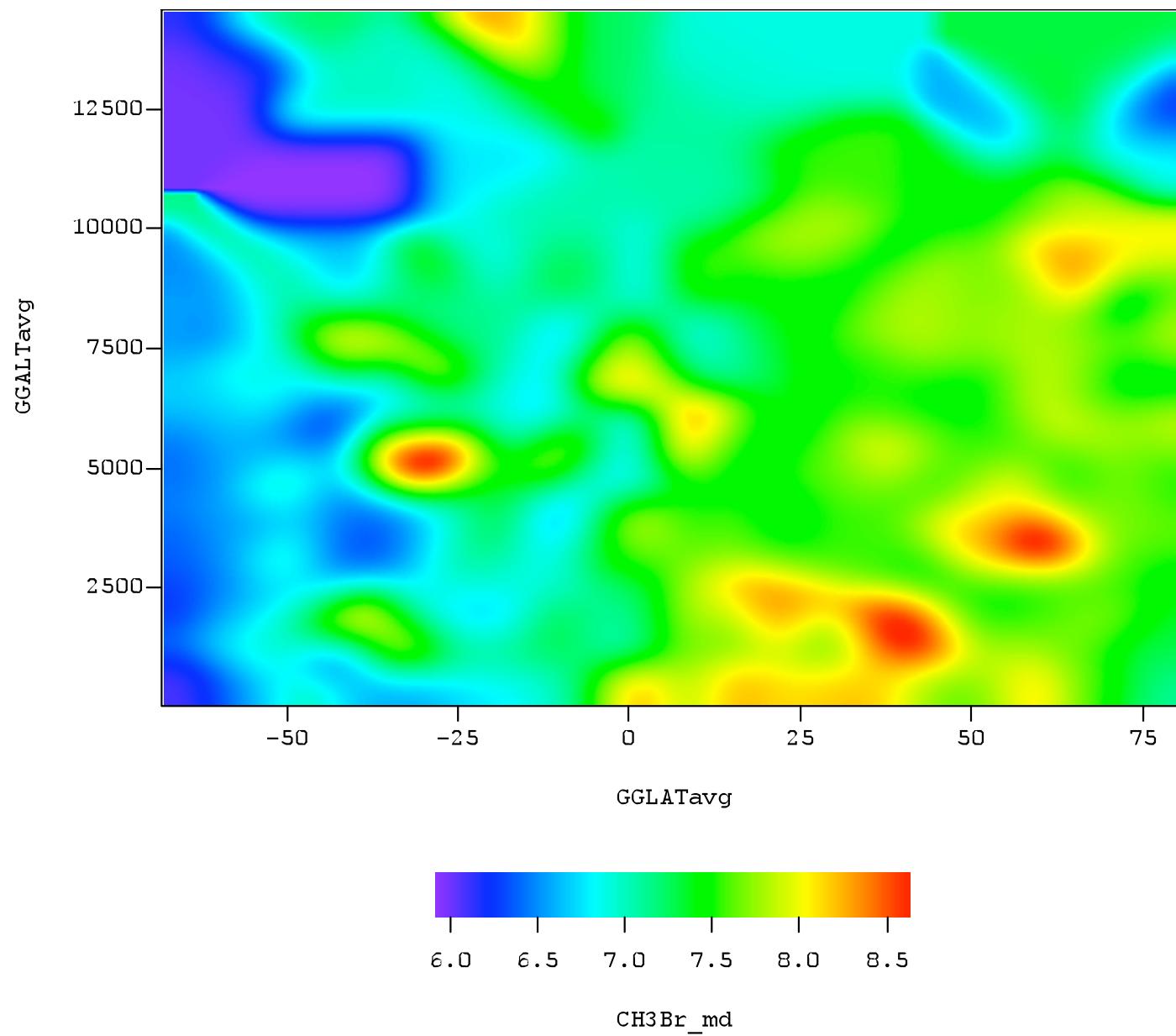
Dichloromethane



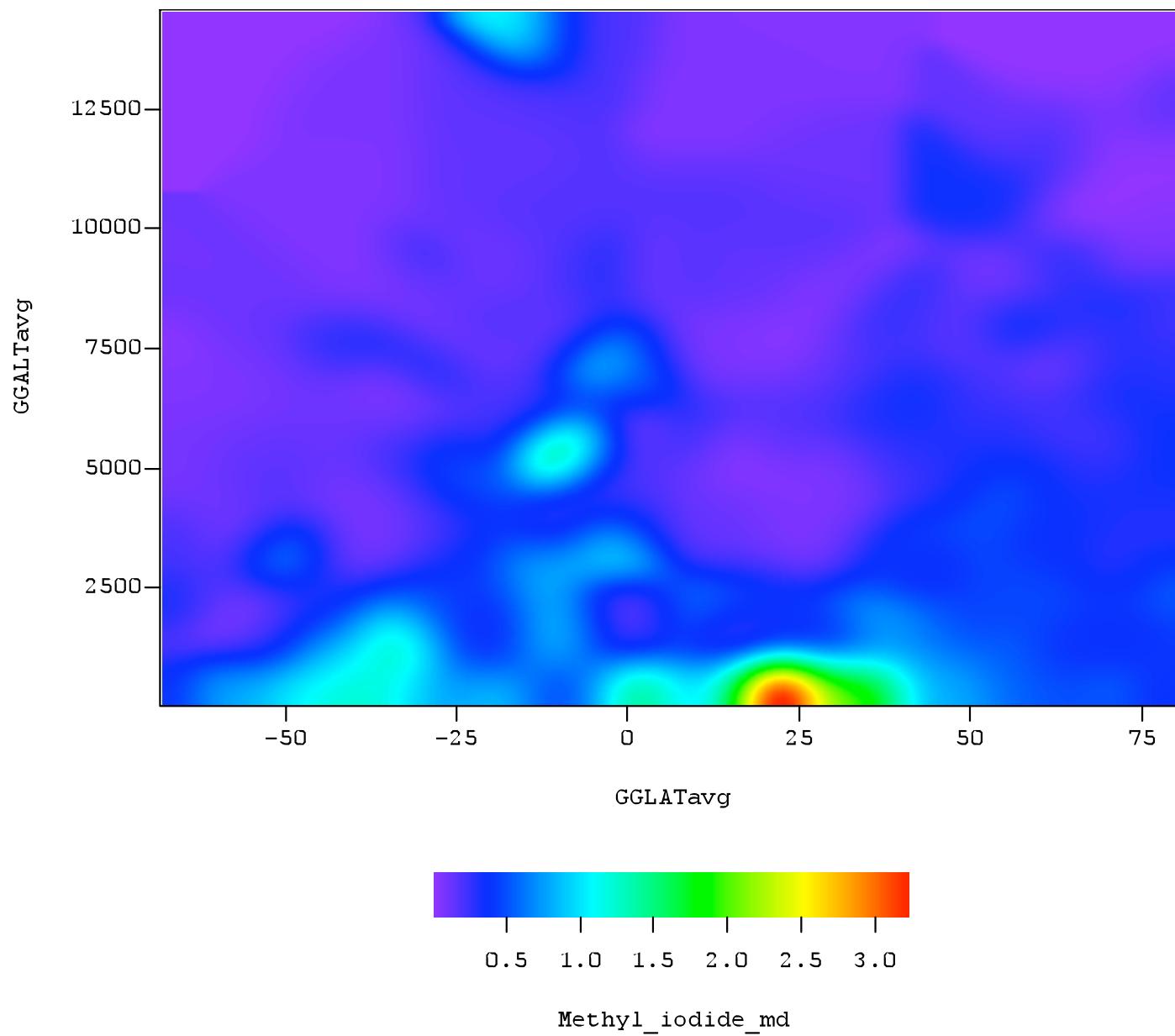
HCFC_123



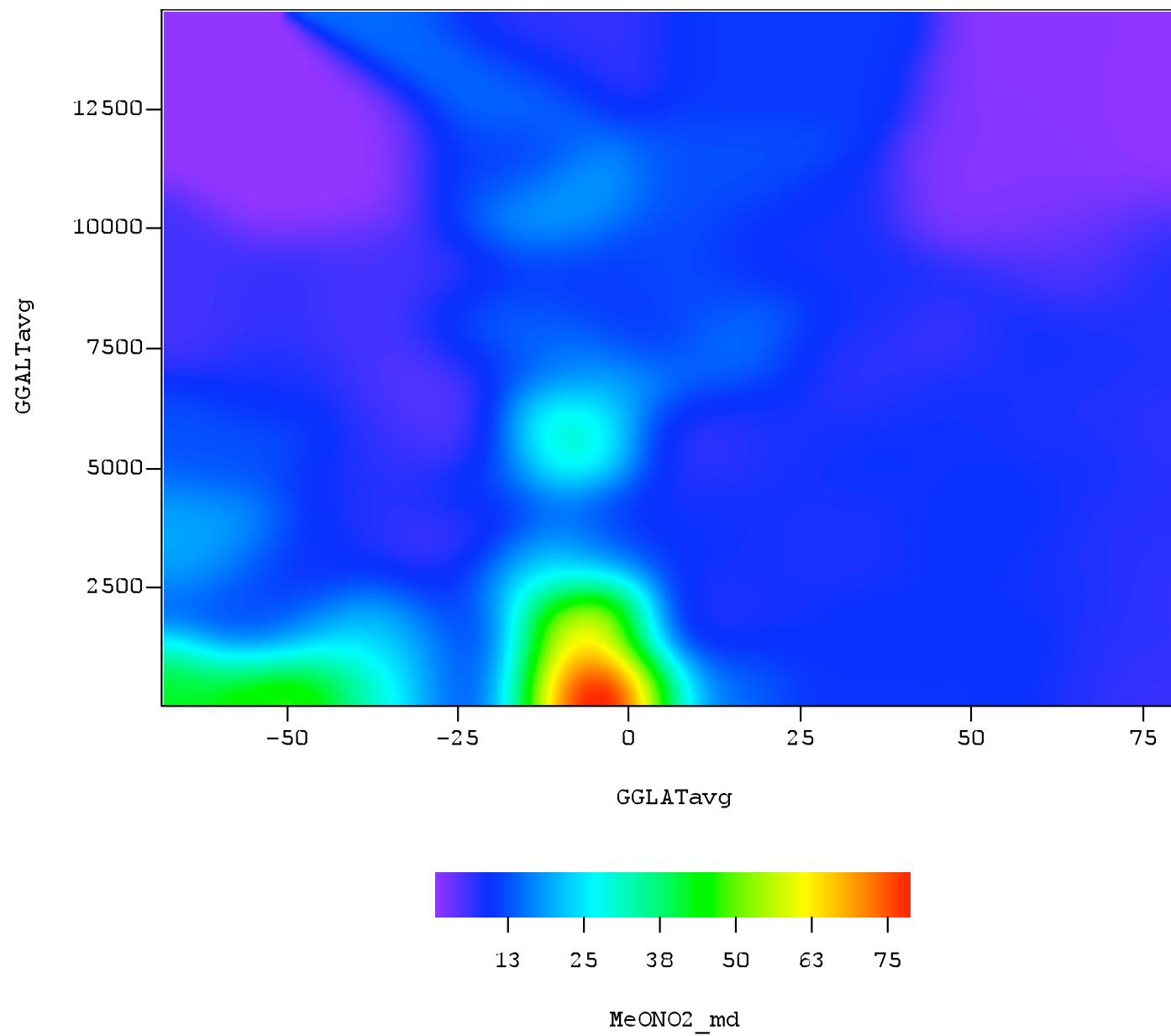
Methyl Bromide



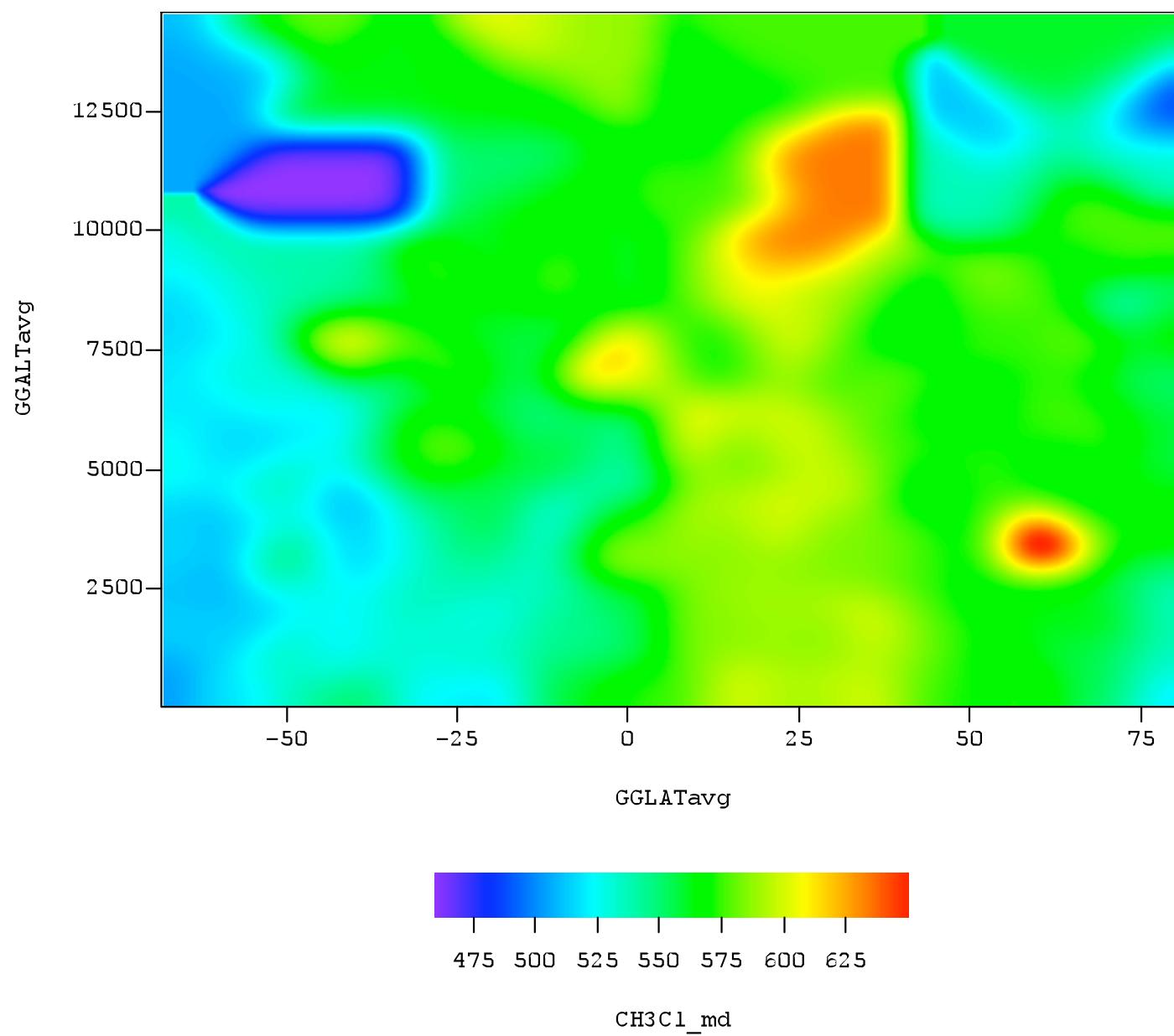
Methyl Iodide



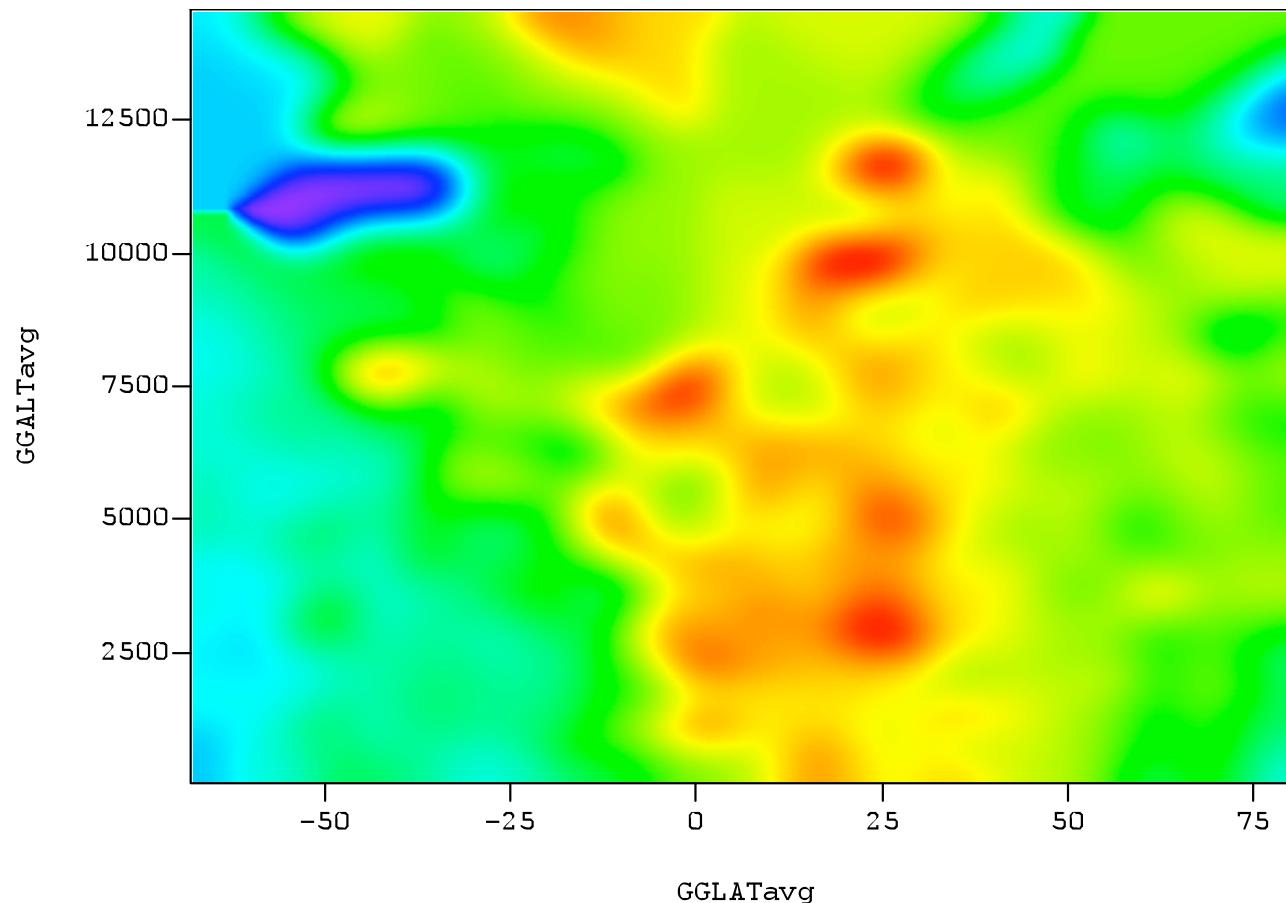
Methyl Nitrate



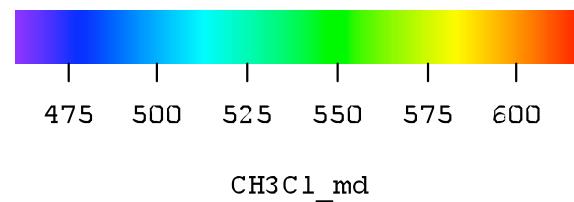
Methyl Chloride



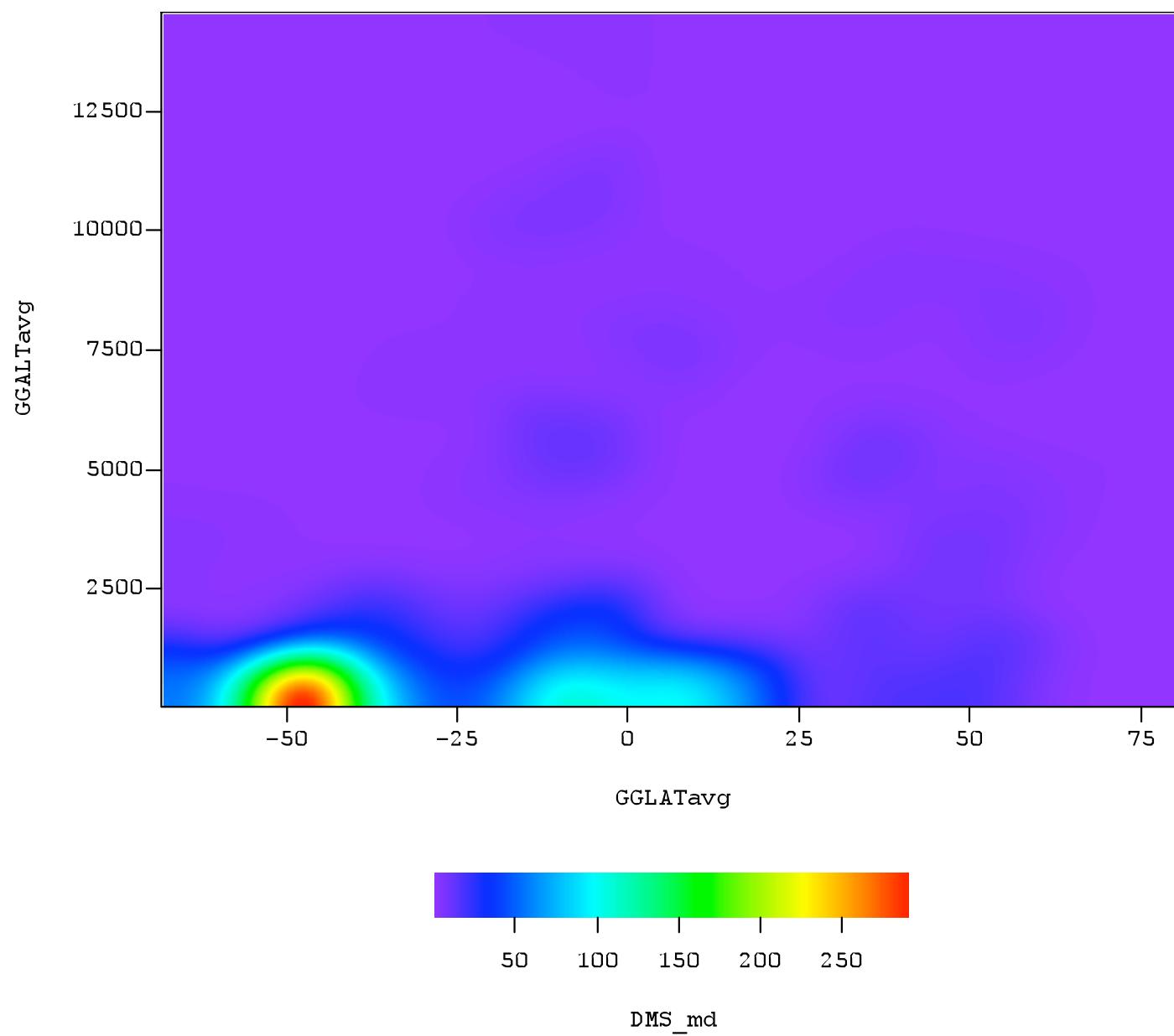
Methyl Chloride



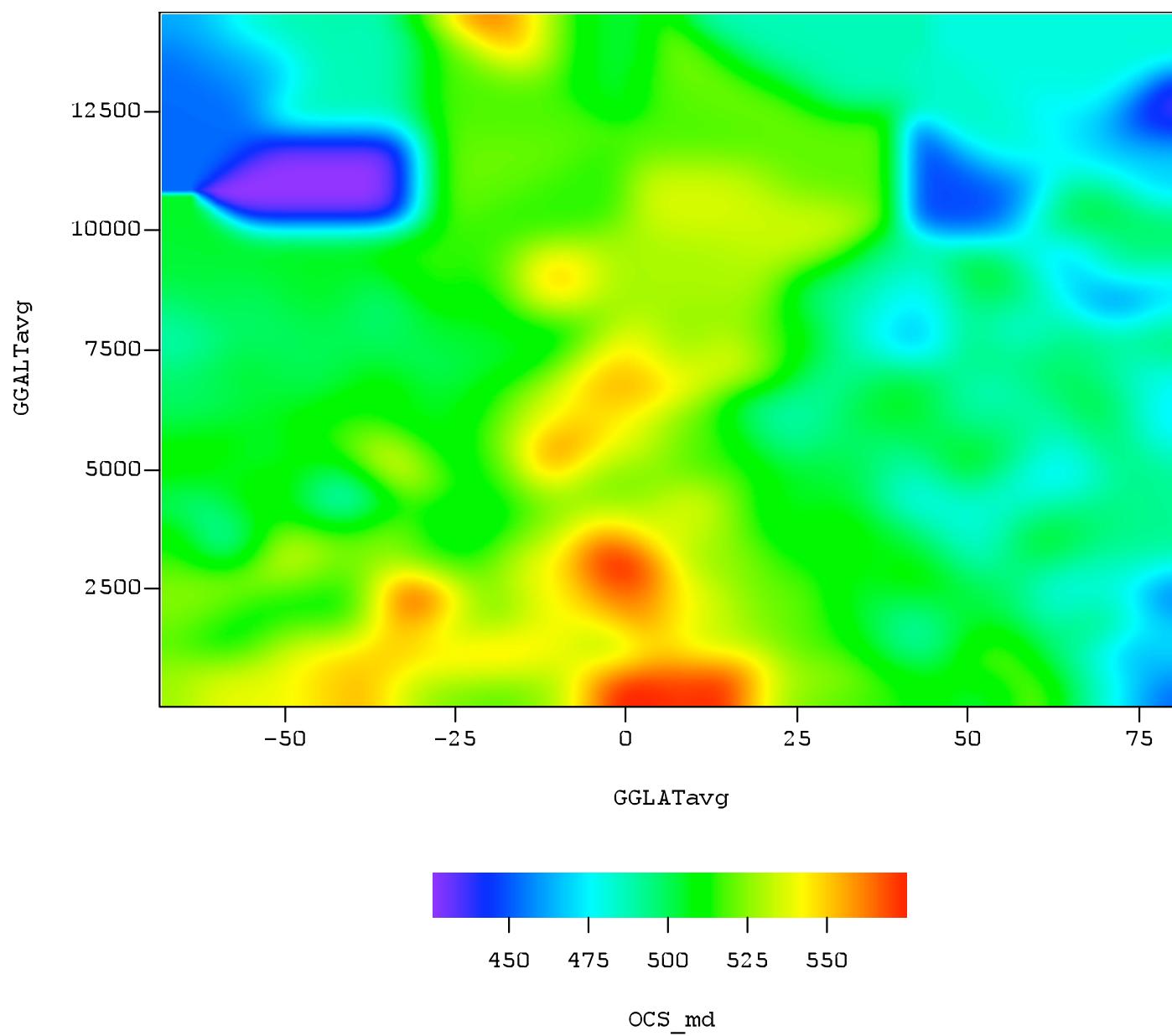
Includes E. Pacific
flight



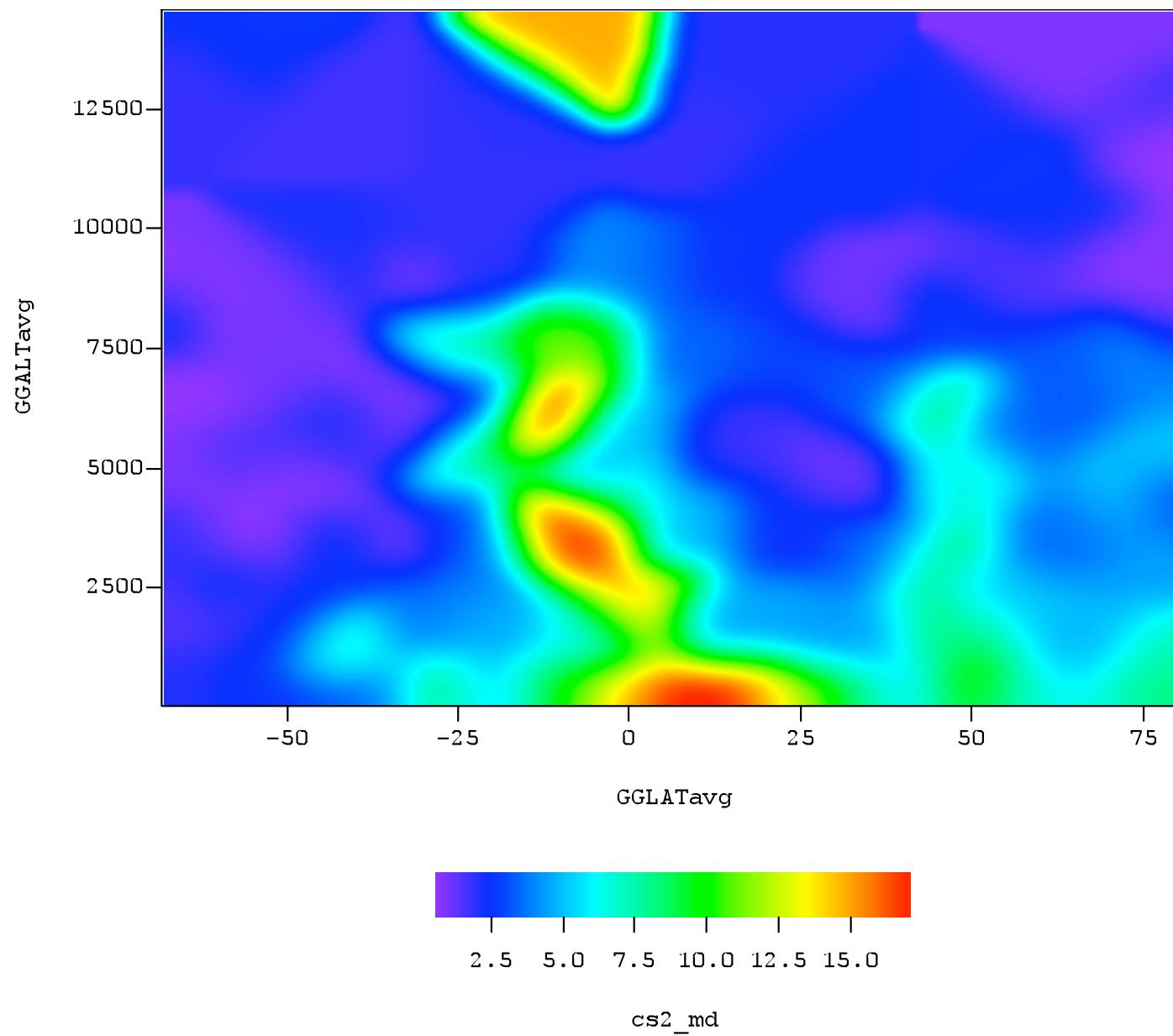
Dimethyl Sulfide



Carbonyl Sulfide



Carbon Disulfide



* HIPPO Team *

Harvard: S. Wofsy, D. Jacob, R. Jimenez, S. Park, B. Daube,
E. Gottlieb, E. Kort, J. Fisher, C. Pickett-Heaps, H. Wang

NCAR-RAF: B. Stephens, P. Romanshkin, T. Campos, J.
Haggerty, GV Crew (*Henry Boynton, Ed Ringleman, pilots*)

NOAA ESRL and CIRES: J. W. Elkins, D. Fahey, R. Gao, F.
Moore, S. A. Montzka, J. P. Schwartz, D. Hurst, B. Miller, J. B.
Miller, S. Oltmans, D. Nance, G. Dutton, R. Spackman, L. A.
Watts, K. Rosenlof, E. Ray; CCG (*E. Dlugocenky, T. Conway,
P. Novelli, A. Andrews, C. Sweeney...*)

Princeton: M. Zondlo JPL: *M. J. Mahoney*

UCSD/Scripps: R. Keeling, J. Bent

U. Miami: E. A. Atlas, R. Lueb

Cooperating modeling groups: ACTM (*Prabir Parat, Kentaro
Ishijima*), GEOS-CHEM, ...others in start-up mode.

Summary and conclusions

- HIPPO provides a new type of data set for CO₂ and GHG studies: global, extremely fine grained, comprehensive tracers
- Some major transport processes are clearly delineated that are not captured well by models—the warm conveyor belt is an example (intense, persistent, ensemble of small scale processes).
- Source regions are revealed.
- The data will be completely public as soon as possible. It will be a great challenge to use them!

It has been a great privilege to work with this dedicated and talented team

